N. F. Brown

ELECTRICAL METERMAN'S HANDBOOK

WRITTEN AND COMPILED BY THE COMMITTEE ON METERS
NATIONAL ELECTRIC LIGHT ASSOCIATION

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PREFACE

The **Electrical Meterman's Handbook** has been prepared for the purpose of making available in practical form and giving wide distribution to, that knowledge of meters and metering which is necessary for the accurate and efficient commercial measurement of electricity.

The need of properly trained metermen is felt by all central stations, both large and small, and the mission of the Handbook is to supply such information as is needed in training men for meter work, together with such instructions and data as every meterman should have constantly at hand for reference.

The Handbook is not intended to cover the same ground as, or in any way to supplant, the **Code for Electricity Meters** prepared jointly by the Meter Committees of the Association of Edison Illuminating Companies and the National Electric Light Association. That work, compiled by an independent laboratory of recognized standing, treated the subject of metering largely from the scientific side and is invaluable as a guide to metering specifications for central station managements, and also for state and civic commissions.

The Handbook is intended primarily for practical metermen and has been prepared with the requirements of men without technical education constantly in mind. While the technical side of the subject has not been neglected, complex mathematical demonstrations have been largely eliminated and simpler but adequate explanations have been given, when the treatment of technical subjects has seemed desirable.

Only modern American electricity meter practice has been considered, or described, no attempt having been made to touch upon foreign usage, or makes of meters.

The Handbook, moreover, is largely a compilation of material from authoritative sources and on this account it is the more valuable. This material includes information on deportment of meter corps; meters; standards; instruments; equipments and methods, and when necessary has been carefully revised. No originality is claimed for a large part of its contents which has been gathered from many sources, the mention of all of which is impracticable. Considerable

material has been taken directly from the Code for Electricity Meters, and also from various reports of the Meter Committee of the National Electric Light Association, particularly from the exhaustive report of 1909, presented by Mr. Geo. Ross Green, to whom credit for the inception of this Handbook is due, and from the reports of the two following years presented by Mr. G. A. Sawin.

The chapter on "The Principles of Electricity Meters" is taken from the excellent paper written by Mr. Burleigh Currier, of Philadelphia, and included in the 1909 report, and has been rewritten by him especially for the Handbook.

The cooperation of other expert metermen has also been secured in the preparation of the work and valuable contributions received from Mr. H. E. Brumelle, Mr. F. V. Magalhaes, Mr. J. R. Wagner, and Mr. Robert B. Grove, of New York; Mr. C. H. Ingalls, of Boston; Mr. Paul Spencer, Mr. J. B. Seaman, and Mr. J. V. Mathews, of Philadelphia; Mr. A. G. Turnbull and Mr. C. E. Brown, of Chicago.

We would also gratefully acknowledge the assistance received from Dr. C. H. Sharp of the Electrical Testing Laboratories, and also from Mr. P. G. Agnew, of the Bureau of Standards of the Department of Commerce and Labor.

Mention should also be made of the ready cooperation of the meter manufacturers who have contributed for publication the data on their respective meters, and particularly of the greatly appreciated assistance of Mr. F. G. Vaughen and Mr. F. P. Cox, of the General Electric Company; Mr. William Bradshaw, of the Westinghouse Electric & Manufacturing Company; Mr. A. A. Serva, of the Fort Wayne Electric Works; Mr. R. C. Lanphier and Mr. H. W. Young, of the Sangamo Electric Company; Mr. Thomas Duncan, of the Duncan Electric Manufacturing Company; Mr. H. I. Shire, of the Columbia Meter Company and Mr. C. I. Hall, of the Chicago Electric Meter Company.

The production of the Handbook in the limited time available was not a small task and would have been impossible had not each member of the Committee carried his full share of the work and devoted considerable time, during the past year, to its preparation. We are especially indebted to Mr. F. A. Vaughn, who, as Secretary of the Committee, has carried the greater part of the burden of its publication.

It is recognized that much of the material in this Handbook will soon become obsolete and, on that account, it would have been desirable to have it published in loose leaf form, so that changes and additions could be made from time to time, but on account of

the wide distribution which is desired for it, this did not seem to be practicable.

It is hoped that the work will be revised and republished at intervals by future Committees, and that it will become a standard publication of the Association, similarly to the **Electrical Solicitors' Handbook,** and, having been prepared in the same spirit of cooperation, that it will likewise prove to be a contribution of some value to the work of the Association.

In conclusion, we desire to express our thanks and obligations to the present administration and especially to the President, Mr. John F. Gilchrist, who has from the start encouraged the production of this Handbook, and to the Executive Committee of the Association, which authorized the large expenditure necessary for its publication.

COMMITTEE ON METERS,

O. J. BUSHNELL, *Chairman.*

CHAPTER I

THE METERMAN'S RELATION TO CONSUMERS

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THE METERMAN'S RELATION TO CONSUMERS

A "Public Service" or "Public Utility" Corporation derives its franchise and its privileges from the community in which it operates. It is therefore, as the name implies, a public servant, selected by the people to perform an essential service, and it is the duty of its employees to **serve the public** as **faithfully, efficiently** and **courteously** as possible.

The operation of a public utility, like the holding of a public office, is in the most positive sense a public trust, and it is exceedingly important that every officer, every head of department and every employee should recognize this fact. Each one owes his employment to the public, as well as to his organization, and should realize that only by doing his full duty to the people of the community can he do his full duty to his company. **The employee** who **serves the public** best is **the employee** who **serves his company** best. The public can just as rightly expect courteous, prompt and pleasant attention from the officers and employees of a company as to expect good service in exchange for the cash it has given and the privileges it has conferred.

The ideal of a corporation—**courtesy** to the public and the best possible **service**—can only be approached through the loyal, alert and intelligent cooperation of every employee. Only the keenest attention and the most assiduous devotion to the company's interests, inspired by a sense of personal responsibility for the success of the business will enable a company to attain that high degree of efficiency comprehended in the term "**best possible service.**"

An employee who is courteous to the public is merely doing his duty and performing the functions which are expected of him and for which he receives his compensation.

The ability displayed by an employee in performing his duties in harmony with the spirit of the organization, with patience and courtesy toward the public, and with an honest effort to do his best, will be an important factor in his progress with the company.

The axiom that "large bodies move slowly" is sometimes, perhaps justly, applied to corporations. **A corporation** is merely **an aggre-**

gation of individuals, and it therefore reflects the human qualities of its constituent parts. It follows that when you find a corporate body is moving slowly, you will also find that **one of its units is moving slowly** and thereby retarding the mass. Every employee should watch himself carefully for symptoms of "lagging" and not allow himself to become a clog on the wheel.

To set down a number of **hard and fast rules** governing a meterman's conduct in relation to his company's consumers is difficult, if not impossible, for no two consumers share the same point of view and no two sets of complaint conditions are exactly alike.

While always bearing in mind the general regulations of the company, a meterman must use his own **ingenuity, judgment and common sense** when dealing with a consumer.

Every man on the company's pay-roll is, in a sense, **a representative of the company.** You often hear it stated that "a man is judged by the company he keeps," and the converse is equally true—companies are judged by the men they keep.

Consider, then, the importance of **your attitude** as a representative of the company, whose aims and ideals find expression through the medium of its employees.

No matter how obscure your position may be, or how remote from the commercial side of the business, you are known amongst your friends and acquaintances—and perhaps by an even wider circle of people with whom you are personally unacquainted—as the **public service company's employee.**

Do not lose sight of the fact that the **consumers** of your company's commodity **regard you** more **as a representative** of the company than as an individual, and will consider the **principles and characteristics** displayed by you while on their premises as **identical** with those of the company.

If, as an employee, you are overbearing and inconsiderate of a consumer's rights or desires, that **consumer** naturally **judges the company by your actions,** which, he assumes, reflect the policy of your company, and he will accordingly make deprecating remarks against the company, in proportion to the unfavorable impression you have made; on the other hand, a courteous meterman can do much to keep up pleasant and profitable relations between consumers and the company.

To a great extent, a company is judged by the "manners" of its employees. Therefore, **cultivate genuine courtesy** and **exercise patience and forbearance** on all occasions.

Courtesy is the outward expression of breeding and character.

Its practice is founded upon the **Golden Rule,** "Do unto others as you would that they should do unto you."

In very few industries is the need of **courtesy** more **imperative** than **in the business** of manufacturing and supplying electric light and power, which, to the layman, is peculiarly technical and mysterious; he does not comprehend its complicated processes, and he resents its apparent mystery. In dealing with this type of man, who cannot understand why he should have a higher bill this month than last, or why the actual reading of the meter should be doubled, or quadrupled, by multiplying the reading by a register constant, employees have **frequent opportunity** for demonstrating the quality of their courtesy.

The importance of building up **the consumer's confidence** in the company, in electricity meters in general and in his meter in particular, should be fully realized, and the straightforwardness, simplicity and accuracy of the company's methods and the reliability of its meters should be made plain to him.

It is necessary for metermen to remember that the consumer is unacquainted with many conditions with which they are thoroughly familiar, and in **imparting** this **knowledge** to the consumer, they should do so **without** any **assumption of superiority** or display of **impatience. Courtesy** to the public **is not condescension** toward the consumer nor is it more than your duty toward the company.

An eminent physician, Dr. Cabot, has called attention to a psychological fact which should constantly be kept in mind by those who have to do with public service, and which he calls **"The Illusion of Routine."**

"You are perhaps an orderly stationed in a certain part of a great institution to answer questions. **People** drift by your corner at such and such a rate and **ask you** questions, many of which are very **foolish questions.** Human nature being what it is, those questions come to be very much alike in any given month, or in any given year, and before you have been there very long you have been asked the same foolish questions by at least a hundred people. The point to which I want to direct your attention is that when **the hundredth man asks** you **a question** which is no more foolish than it was when it was asked you the first time, **your impression is,** and you act upon it, that **you have been asked** the same foolish question **a hundred times by the same man.**"

The **favorable impression** made upon a consumer who starts to register a vigorous complaint, and who finds he is confronted by a courteous employee, quick to understand his difficulties and eager to

remedy them, cannot be overestimated. From being one of its **severest critics,** the consumer **becomes** one of the company's **best friends;** he is usually gratified to recognize the courtesy with which he has been treated, and does not hesitate to advertise it amongst his friends.

The **kind of service** a consumer receives is even **secondary** to the **kind of treatment** his sensibilities receive. If he believes the company treats him with respect and fairness he is more willing to be fair and reasonable in his service requirements. But if he bears a wounded pride, or is incensed against the company by an inconsiderate employee, the best of service and the lowest of rates may not suffice to pacify him.

True courtesy pays:

1. Because it makes friends for the company, as well as for the employee.
2. Its practice is conducive to greater dignity and self-respect.
3. It eliminates friction and lubricates the machinery of business.
4. It refutes the traditional attitude, popularly ascribed to public service corporations, of being callously indifferent to the interests of their patrons.

Courtesy and civil treatment are due fully as much to those with **small installations as to the largest consumer. Promises to patrons** and public should be carefully considered before they are made, in the light of the fact that **disappointment and dissatisfaction go hand in hand.** Only authorized employees should make definite promises.

Be as **brief** as the occasion will warrant, but in order to be brief it is **not** necessary to be **brusque;** sharp, **peremptory answers** and remarks cannot be too **severely condemned.** In the practice of brevity, it is only necessary to be business-like and concise.

In conversation with consumers, **use diplomacy.** The assumption must be made that **the consumer is correct** in his statements, and the **burden of proof** must be **assumed by you** and the company. The consumer must be made to plainly feel this attitude. Always bear in mind, if a dispute arises, that, in giving technical information, you are apt to be misunderstood or misquoted. Use great care in choosing answers regarding the results of your work. It were better to politely refer the interrogator to the main office than to give a premature decision, from unchecked calculations or inferences, or to overstep your authority on account of the **possession of** too much **false pride** to acknowledge that you do not know, or that another department is authority on that particular question.

On the consumer's premises your work should be conducted in a

quiet, earnest, business-like manner, laying all **frivolities aside** for leisure moments. Avoid discommoding the consumer and being unfair to the company in the consumption of unnecessary time in the pursuit of your duties. If the situation is difficult, or complex, exercise the best quality of judgment at your command as to whether an unavoidably long time should be spent upon the problem at that time, or another visit, with attending inconvenience to the consumer, should be made with more efficient equipment or preparation.

By a **conscientious, business-like attitude** and conduct on the consumer's premises, you can eliminate the embarrassment and possibility of suspicion, or accusations.

The **report** of **accidents** to the consumer's property, **immediately,** correctly, and in detail, will save the company, and the meterman, the embarrassment of misinterpreted accusations and further difficulty resulting from lack of knowledge of the circumstances, and will place the company in position to deal with the case directly and with dispatch.

Personal injuries, in which the company is interested, **should be reported** as soon as possible, as this will give the injured one the benefit of whatever medical service is at the command of the company and will allow the company to relieve the incapacitated, or sick, employee, and to continue the work with minimum interruption.

The **use of bad language, and tobacco** in any form, or the display of any **habits,** or characteristics, which may be **disagreeable to the consumer** should be studiously avoided.

Sometimes, unfortunately, it seems necessary to caution metermen against such **thoughtless misdemeanors** as leaving open doors and windows found closed; slamming doors; tracking mud and dirt into the interior of the consumer's premises; disarranging furniture and leaving it so; and entering the house without the observance of such conventionalities as the removal of a hat or cap, or using the rear, or other, entrances provided for you.

Avoid as much as possible the **disconnection of lights,** the disuse of which may inconvenience the consumer; and if it be necessary to disconnect certain circuits, or units, **be** particularly **careful to reestablish** every **connection** you disturb; to turn off any lights, or circuits you found necessary to use during your investigation, and to leave the consumer's property as you found it.

Bear in mind that **you are an outsider** in premises which do not belong to you, but to the consumer, and do not take liberties on his property which you would not tolerate in reverse circumstances.

It is essentially to **your advantage,** as well as to that of the com-

pany, that you **be neat and cleanly** in personal appearance. Good first impressions assist materially.

Your badge, or other **means of identification,** is given you for an obvious, specific purpose, and no resentment should be fostered when the consumer asks you to **identify yourself;** in fact, you should make such a situation impossible by immediately explaining your mission in a business-like, intelligent, unassuming manner, and utilizing such credentials as your company has furnished you.

In conclusion, it may be stated that a meterman, therefore, has a **three-fold responsibility** placed upon him, namely, **his duty to his employer** to see that all the energy used is measured; **his duty to the public** to see that they are not required to pay for more energy than they have used; and **his duty to himself** that he turn out good and accurate work, and thus build up his own reputation and strengthen his chances for promotion and prosperity with his company.

CHAPTER II

TERMINOLOGY, NOMENCLATURE AND UNITS

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TERMINOLOGY

DEFINITIONS OF TECHNICAL TERMS

Accumulator—A word sometimes applied to a current accumulator. A Leyden jar, or condenser. A secondary, or storage, battery.

Admittance—The reciprocal of the impedance in an alternating current circuit.

Alive—A name sometimes given to a live wire, or circuit. An active wire, or circuit.

Alternating Current—Currents which flow alternately in opposite directions, similarly to the ebb and flow of tides. Current whose direction is periodically reversed and which when plotted, consists of half-waves of equal area in successively opposite directions from the zero line. An alternating current equals the electromotive force divided by the impedance, or

$$I = \frac{E}{Z} = \frac{E}{\sqrt{R^2 + X^2}} = \frac{E}{\sqrt{R^2 + (L\omega - \frac{1}{C\omega})^2}}$$

This expression represents Ohm's law for alternating currents.

Z = Impedance of circuit in ohms.

R = Resistance of circuit in ohms.

X = Reactance of circuit in ohms.

L = Coefficient of self induction in henrys.

C = Capacity of the circuit in farads.

$\omega = 2\pi f$ angular velocity, where

f = the number of cycles per second, or frequency.

Alternating Current, Collection of—If a coil is revolved in a uniform magnetic field, the number of lines threading through it will twice in each revolution be zero, once a maximum in one direction, and once in the other. If, therefore, the current of that coil is collected by means of collector rings and brushes, Figs. 1 and 2, it will traverse the external circuit, from brush to brush, in one direction for one half of a revolution and in the opposite direction in the

other half, or an alternating current is produced by the coil. In plotting the positions of the coil in the magnetic field as ordinates and the

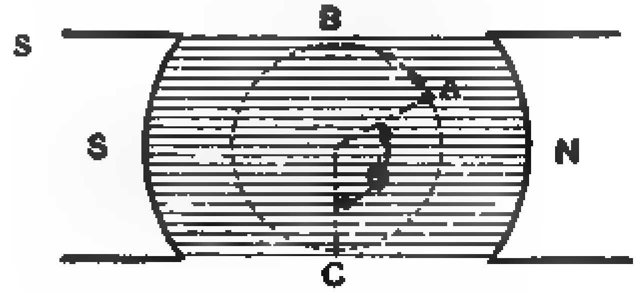


FIG. 1.—Revolution of a Coil in a Uniform Magnetic Field

corresponding instantaneous values of the induced e. m. f. as abscissæ, the curve of the induced e. m. fs., or, since the electrical resistance of the circuit is constant during the motion of the coil, the curve of induced

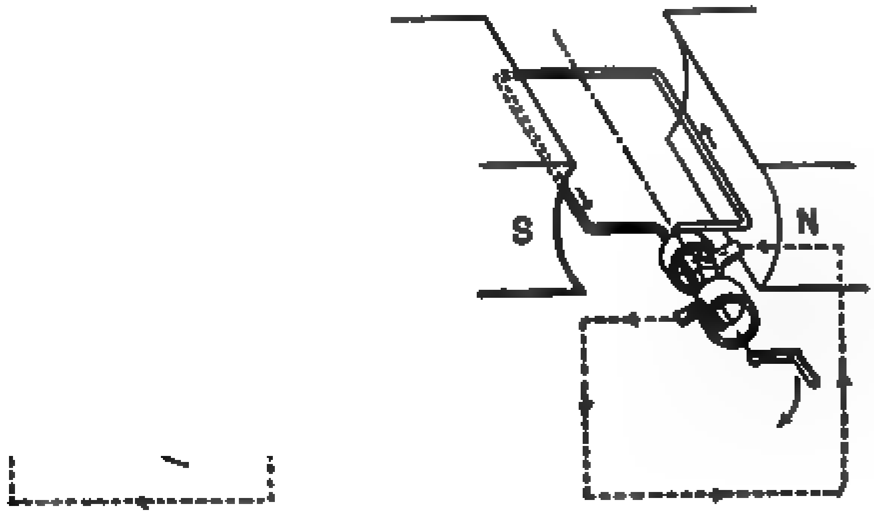


FIG. 2.—Collection of Alternating Current.

currents, is obtained (Fig 3). Since the instantaneous value $e\phi$ at any moment is expressed by the product of the maximum value and the sine of the angle through which the coil has moved, viz., $e\phi =$

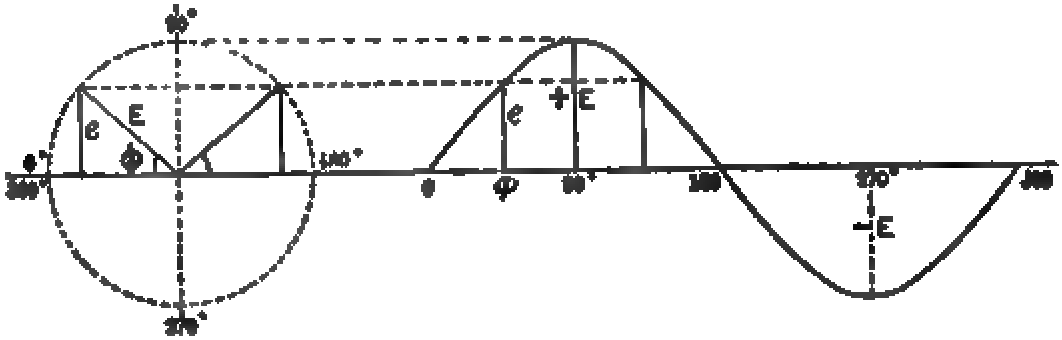
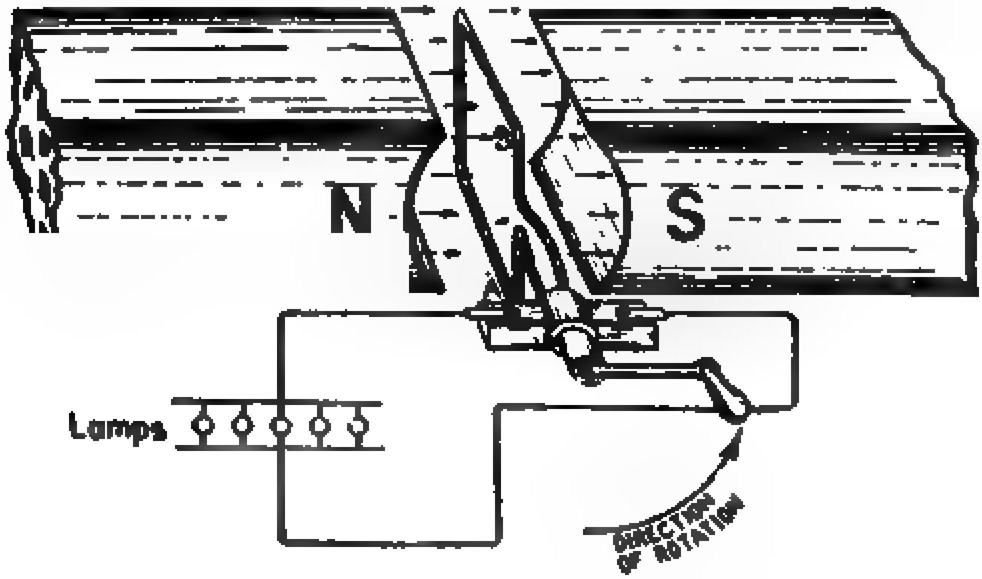


FIG. 3.—Development of Alternating Current Sine Wave



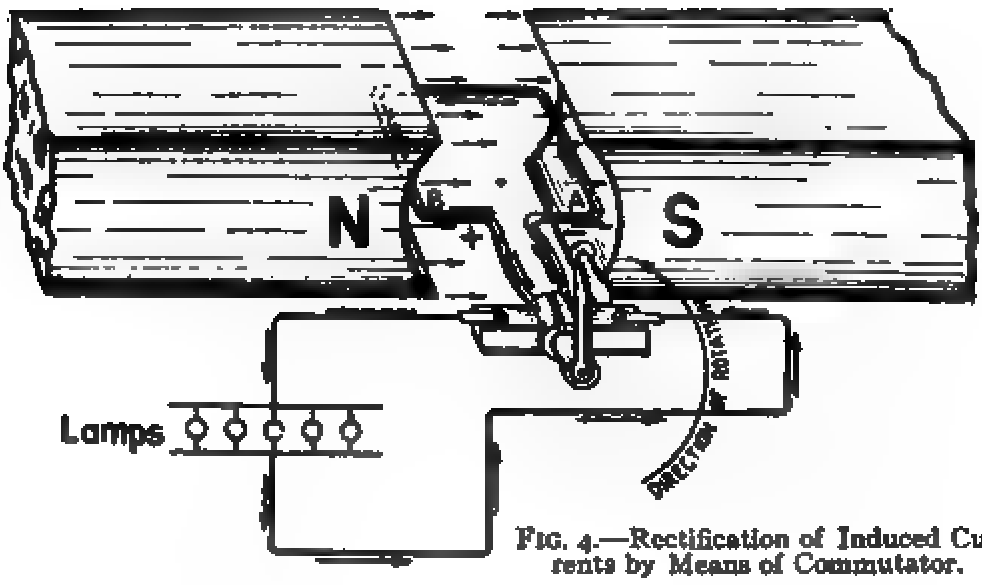


FIG. 4.—Rectification of Induced Currents by Means of Commutator.

E × sin ϕ, the curve of the induced e. m. fs., in a uniform magnetic field, is a sine wave, or a sinusoid.

Alternating Currents, Rectification of—By means of a device called a commutator, the alternating current delivered by the coil to the

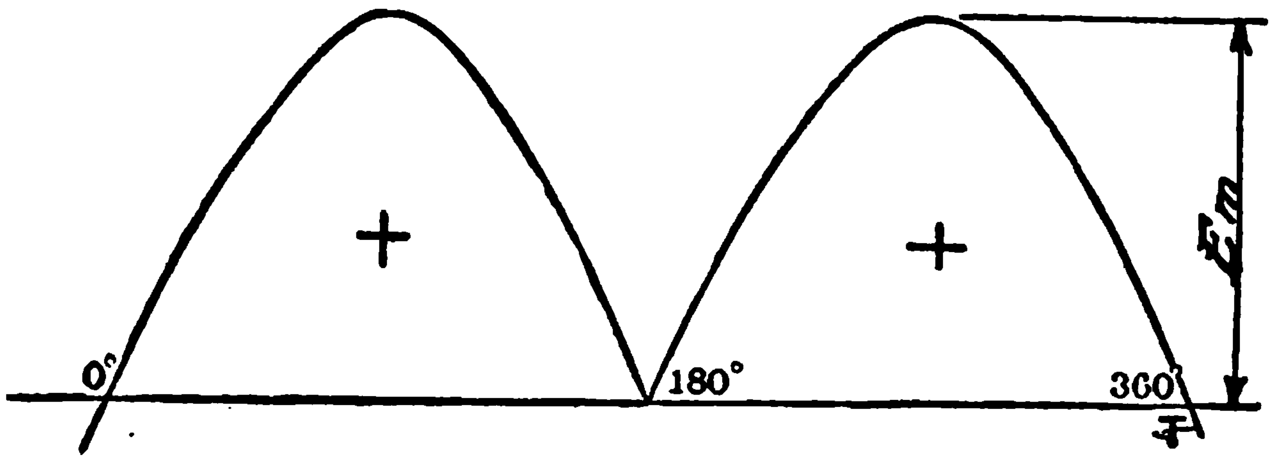


FIG. 5.—Rectified e. m. f. Developed by an Armature with a Single Coil.

external circuit can be rectified so as to flow always in the same direction, the negative inductions being commutated into positive ones, and the alternating current transformed into a unidirected or continuous current. This is shown in Fig. 4, Fig. 5 and Fig. 6.

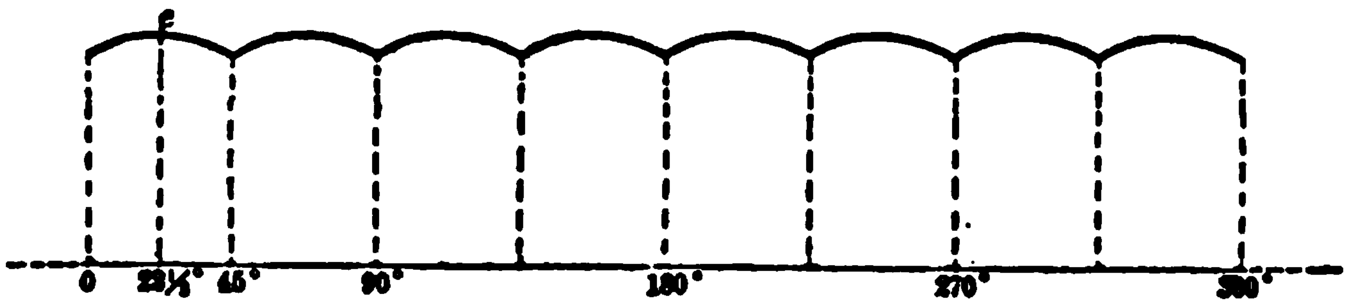


FIG. 6.—Rectified e. m. f. Developed by an Armature with Many Coils.

Alternator, or Alternating Current Generator—A generator which produces alternating currents, either single-phase or polyphase.

Ammeter—A form of galvanometer in which the value of the current is measured directly in amperes.

An ammeter is a galvanometer with an indicator which plays over a divided scale and indicates, directly, the value of the current flowing through the instrument. In many cases a small but definite fractional part only of the current flows through the ammeter, the remainder flowing through a low resistance shunt. The numbers on the ammeter scale may be made to give the value of the total current including that which flows through the shunt. If desired, the instrument may be provided with several interchangeable shunts of different resistances, so that the instrument may be used to measure large or small currents at will. In such a case the scale readings must be

multiplied by a factor to give the total current, and this factor has a large value for a low resistance shunt and a small value for a high resistance shunt.

There are five distinct types of ammeters, namely:

(*a*) The tangent galvanometer type, in which the indicator is attached to a small permanent magnet which is deflected by the current to be indicated. This type is now seldom used (Fig. 7).

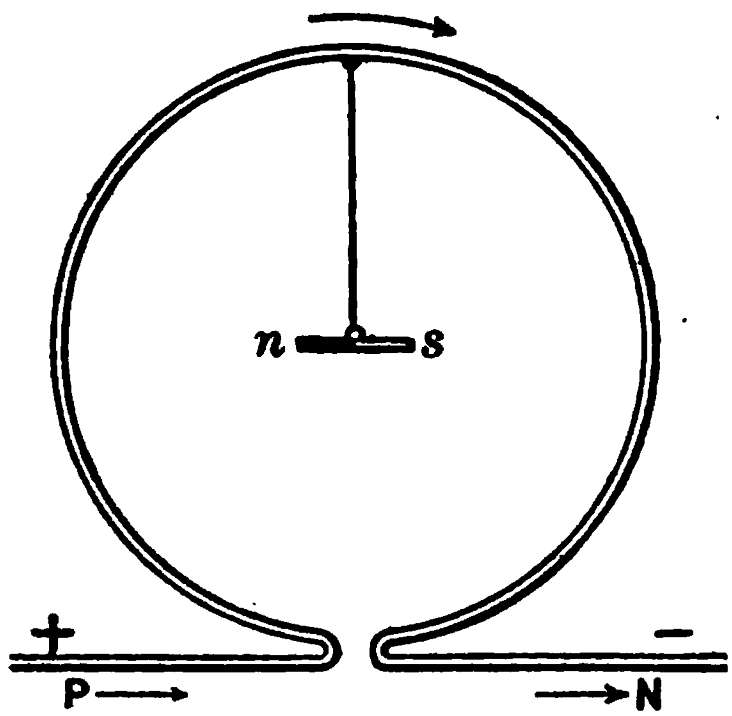


FIG. 7.—Tangent Galvanometer.

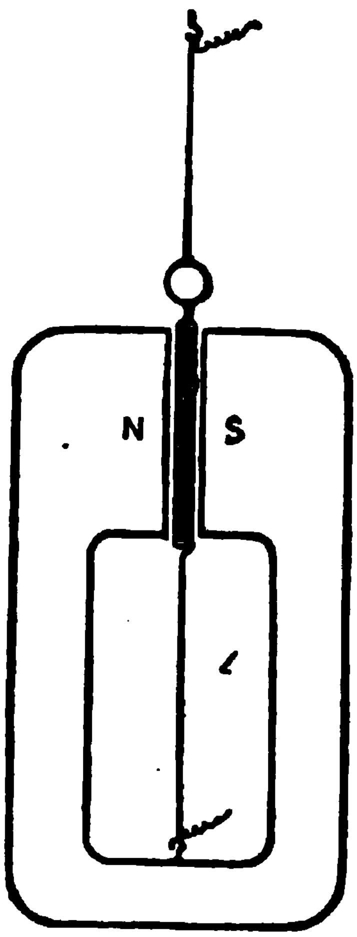


FIG. 8.—D'Arsonval Galvanometer.

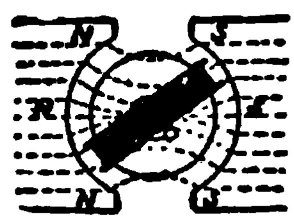


FIG. 9.—D'Arsonval Type of Continuous Current Instrument.

(*b*) The D'Arsonval galvanometer type, in which the current to be indicated (or a definite fractional part of it) flows through a small suspended or pivoted coil which is deflected by a permanent steel magnet. The indicator is attached to the pivoted coil (Fig. 8). This type is much used for precision ammeters for continuous currents. The Weston continuous current ammeters are of this type (Fig. 9).

(*c*) The electrodynamometer type, in which the current to be indicated (or a definite fractional part of it) flows through a stationary coil and a movable (pivoted) coil connected in series. The force action between the two coils deflects the pivoted coil and causes an attached indicator to play over a divided scale. This type is much used for precision ammeters for alternating current; it is suitable also for continuous current, but it has the disadvantage that the deflecting

forces are small, so that the instrument must be very finely constructed. Another disadvantage of this type when used for continuous currents is that the direction of deflection is not reversed by a reversal of the current (Fig. 10).

(*d*) The hot wire type, in which the current to be indicated flows through a fine wire, which by its rise of temperature and consequent expansion, actuates an indicator which plays over a divided scale. (See hot wire measuring instrument.)

(*e*) The plunger type. This type includes all of the great variety of ammeters in which a piece of soft iron is magnetized and deflected by a coil of wire through which the current to be indicated, flows. The simplest form of the plunger type of ammeter is that from which it takes its name, namely, a coil of wire and a soft iron plunger which

FIG. 10.—Electrodynamometer Type of Indicating Instrument.

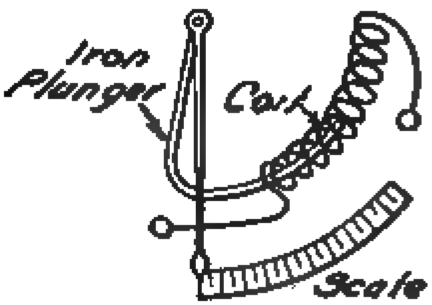


FIG. 11.—Plunger Type of Indicating Instrument.

is drawn into the coil by the current, in opposition to the pull of a spring or to the pull of gravity (Fig. 11). In the most approved form of plunger ammeter, a soft iron vane is attached to a pivot which is controlled by hair springs, and the instrument is so designed as to magnetize the soft iron vane strongly, even when the current

to be indicated is a small fraction of that which gives a full deflection of the instrument. This accomplishes the double purpose of making the deflections more nearly proportional to the current, and of eliminating the errors due to magnetic hysteresis, that is, to the tendency of the iron vane to retain its magnetism with a decreasing current.

Ampere—The international ampere, as defined by the International Electrical Congress, which met in Chicago in 1893, "is one-tenth of the unit of current of the c.g.s. system of electromagnetic units, and is represented sufficiently well for practical use by the unvarying current, which, when passed through a solution of nitrate of silver in water and in accordance with an adopted set of specifications, deposits silver at the rate of 0.001118 of a gram per second."

Ampere-Hour—A unit of electrical quantity equal to the quantity of electricity conveyed by one ampere flowing for one hour. A quantity of electricity equal to 3,600 coulombs.

Ampere-Hour Meter—An instrument giving the total time summation of the amperes. (See Chapter XVI and Chapter III.)

Ampere-Second—A unit of electric quantity equal to the quantity of electricity conveyed by one ampere flowing for one second. A coulomb.

Ampere Turn—A unit of magneto-motive force equal to that produced by one ampere flowing around a single turn of wire.

Amplitude of Vibration of Wave—The extent of the excursion of a simply vibrating particle, or quantity, on either side of its vibrating point.

Angle of Declination—The angle which measures the deviation of the magnetic needle to the east, or west, of the true geographical north. The angle of variation of a magnetic needle.

Angle of Dip—The angle which a magnetic needle, free to move in both a vertical and horizontal plane, makes with the horizontal line passing through its point of support. The angle of inclination of a magnetic needle.

Angle of Inclination—The angle of dip.

Angle of Lag or Lead of Current—An angle whose tangent is equal to the ratio of the reactive to the ohmic resistance in a circuit; whose cosine is equal to the ohmic resistance divided by the impedence of a circuit; whose cosine is the ratio of the real to the apparent power in an alternating current circuit or the angle by which the current lags behind or leads the e. m. f.

Angle of Lead of Commutator Brushes—The forward angular deviation from the normal position which must be given to the col-

lecting brushes on the commutator of a continuous-current generator in order to obtain sparkless commutation.

Anion—The electro-negative ion, or radical, of a molecule.

Anode—That electrode by which the current enters an electrolyte is called the anode.

Aperiodic Instrument—An instrument whose indicator comes to rest without any oscillation. A dead-beat instrument.

Apparent Electromotive Force—The e. m. f. apparently acting in a circuit as measured by the drop of pressure due to the resistance of the circuit and the current strength passing through it.

Apparent Power, Volt-Amperes—In an alternating current circuit, the apparent power, or the product obtained by multiplying the volts by the amperes, as read directly from a voltmeter and ammeter, $\frac{\text{Power}}{\text{Power-factor}}$ = apparent power. When the power-factor is unity the apparent power in volt-amperes is equal to watts.

Apparent Resistance—The impedance in an alternating current circuit, or portion thereof. (See impedance.)

Apparent Watts—The apparent power in an alternating current circuit as distinguished from the real power.

Armature—A mass of iron, or other magnetizable material, placed on or near the poles of a magnet.

That part of a dynamo, motor or continuous current meter which carries the wires that are rotated in the magnetic field.

Astatic—A magnet so arranged with another as to be devoid of directive power is said to be astatic, that is, it will remain still in whatever position it is mechanically placed. (See astatic pair.)

Astatic Couple or Pair—If two magnets (Fig. 12) be taken equal in length and in strength of pole, and fixed together by a stout piece of wire or other rigid connection, with their magnetic axes parallel and their similar poles pointing opposite ways, they will form what is variously termed an astatic pair, astatic combination, or astatic needles. For if such a combination is suspended by the middle, so as to be free to move in a horizontal plane, the two magnets satisfy or neutralize one another. The earth's attractive force on the north pole of one needle is exactly counterbalanced by its repelling force on the south pole of the other needle, and consequently there is no directive force to cause the combination to set in any particular position.

Astatic Galvanometer—A galvanometer provided with an astatic needle, or circuit (Fig. 12 and Fig. 13).

Automatic Circuit Breaker—A device for automatically opening a circuit when the current through it exceeds a predetermined limit.

Auto-transformer—A one coil transformer consisting of a choke coil connected across alternating current mains, and so arranged that a current, or potential, differing from that supplied by the mains can be obtained from it by tapping the coil at different points. Called also a compensator. A transformer in which a part of the primary winding is used as the secondary winding or conversely.

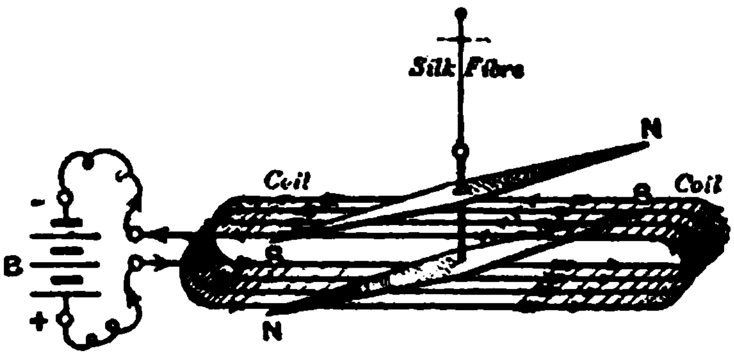


FIG. 12.—An Astatic Couple.

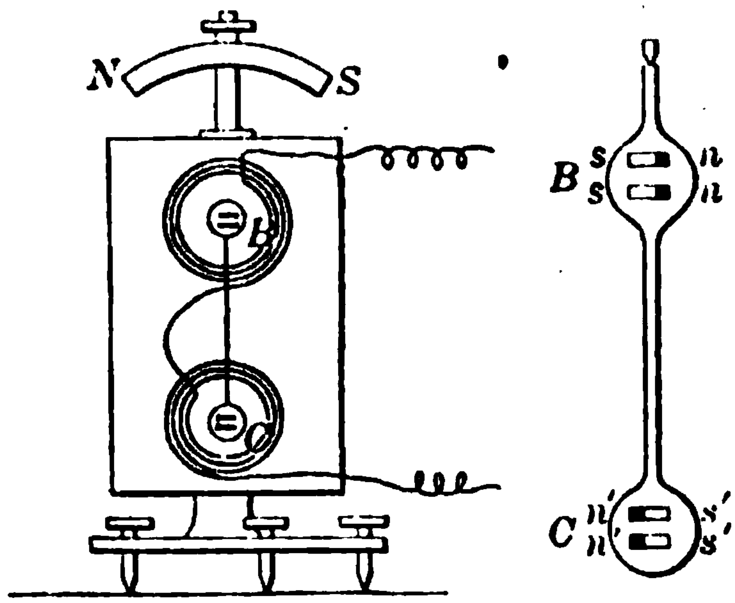


FIG. 13.—An Astatic Galvanometer.

Axes of Co-ordinates—The vertical and horizontal lines usually intersecting each other at right angles, and called respectively the axes of ordinates and abscissæ, from which the co-ordinates of a point on a curve are measured.

Axis of Magnetic Needle—A straight line drawn through a magnetic needle, and joining its poles.

Balanced Load of System—Any system is said to be balanced when all conditions of each of the circuits of a polyphase, or n-wire, system are alike and numerically equal.

Balanced Resistance—A resistance so placed in a bridge or balance as to be balanced by the remaining resistances in the bridge.

Ballistic Galvanometer—A galvanometer designed to measure the total quantity of electricity in a discharge lasting for a brief interval, as, for example, the current caused by the discharge of a condenser. A galvanometer, in which the movable part is as little damped as possible, suitable for measuring electric charges or discharges, and usually adjusted to have a long period of vibration or slow swing.

Bank of Lamps—A group of electric lamps collected together in a common structure, usually for the purpose of obtaining a load.

Battery—If a number of simple cells are united in series, the zinc plate of one joined to the copper plate of the next, and so on, a

greater difference of potentials will be produced between the copper "pole" at one end of the series and the zinc "pole" at the other end. Hence, when the two poles are joined by a wire there will be a more powerful flow of electricity than one cell would cause. Such a combination of cells is called a battery.

Bifilar Suspension—Suspension by means of parallel vertical wires, or fibers, as distinguished from suspension by a single wire, or fiber.

Bifilar Winding—The method of non-inductive winding, employed in resistance coils to obviate the effects of self-induction, in which the wire, instead of being wound in one continuous length, is doubled on itself before winding.

Binding Post—A metallic binding screw, rigidly fixed to some apparatus or support, and employed for conveniently making firm electric connections.

Branch Conductor—A conductor placed in a branch, or shunt, circuit. A smaller, or sub-conductor, tapping a main.

Bridge, Wheatstone—A device whereby an unknown electric resistance is readily measured. A device for measuring an unknown

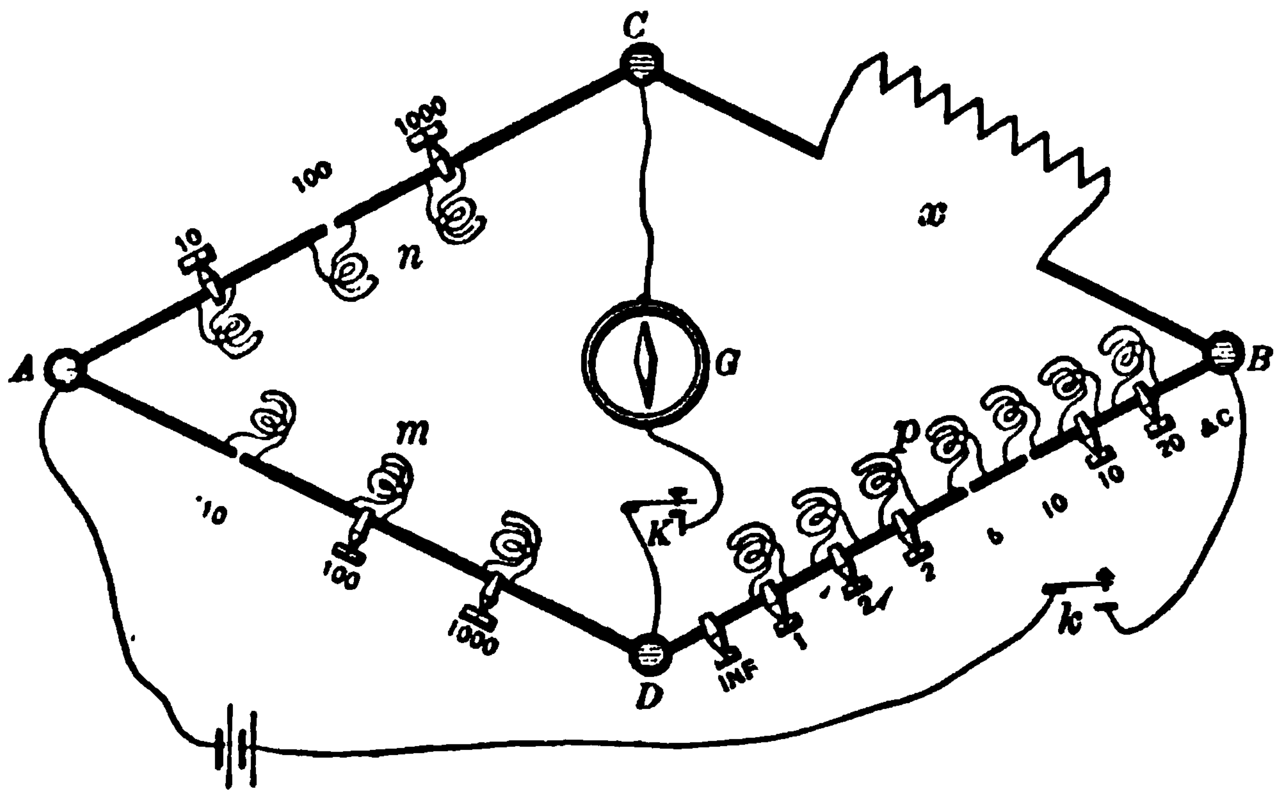


FIG. 14.—Diagram of Connections of a Wheatstone Bridge.

resistance by comparison with two fixed resistances and an adjustable resistance. Suppose that *x* is the resistance to be determined in Fig. 14. The other three arms are built up from the coils of a standard resistance box. The arms, *m* and *n*, are called the "resistance arms" and are so cut into the circuit by the removal of plugs that the ratio between their resistances is a decimal, as 10 or 100, thus simplifying the solution of the proportion. To illustrate, suppose that the resist-

ance of *m* is 10 ohms; that of *n*, 100 ohms; and that of *p*, 15 ohms, as represented in Fig. 14. Then the resistance of *x* is 150 ohms. If the resistance of *n* is 10 ohms; that of *m*, 100 ohms, and that of *p*, 464 ohms, the resistance of *x* is 46.4 ohms. In using the bridge, the battery circuit should always be made by depressing the key, *k*, before *K*, the key of the galvanometer branch is depressed. This avoids the sudden "throw" of the galvanometer needle, in consequence of self-induction, when the circuit is closed.

Bridge Wire—The wire in a Wheatstone bridge in which the galvanometer is inserted.

Brushes of Dynamo Electric Machines—Strips of metal, bundles of wire, wire gauze, slit plates of metal, or plates of carbon, that bear on the commutator of a dynamo, motor or meter for carrying off the current generated by, or for conveying current to, the armature.

Burn Out—The destruction of an armature, or any part of an electric apparatus, by the passage of an excessive current due to short-circuit or other cause.

Busbars—The heavy metallic bars to which dynamo leads are connected and to which the outgoing lines, etc., are connected.

Capacity, Current Carrying—The following table gives the maximum current carrying capacities of rubber insulated wires permissible under the National Electric Code requirements.

B. & S. Gauge Number	Amperes	Circular Mils	Amperes
18	3	300,000	270
16	6	400,000	330
14	12	500,000	390
12	17	600,000	450
10	24	700,000	500
8	33	800,000	550
6	46	900,000	600
5	54	1,000,000	650
4	65	1,100,000	690
3	76	1,200,000	730
2	90	1,300,000	770
1	107	1,400,000	810
0	127	1,500,000	850
00	150	1,600,000	890
000	177	1,700,000	930
0000	210	1,800,000	970
		1,900,000	1,010
		2,000,000	1,050

Capacity, Electric—Relative ability of a conductor, or system, to retain an electric charge. See farad.

Capillary Electrometer—An electrometer in which difference of potential is measured by the movements of a drop of sulphuric acid in a tube filled with mercury.

Carbon Rheostat—An adjustable resistance formed of carbon plates, or powder, whose resistances can be varied by pressure.

Cardew Voltmeter—A voltmeter whose indications are obtained by the expansion, due to heating, of a long fine wire by the passage through it of the current to be measured.

Cathode—That electrode by which the current enters an electrolyte is called the cathode.

Cell, Electrolytic—A cell or vessel containing an electrolyte in which electrolysis is carried on.

An electrolytic cell is called a voltameter when the value of the current passing is deduced from the weight of the metal deposited.

Center of Distribution—In a system of electrical energy distribution, any point at which the supply current is branched, or radially distributed, to mains, to submains, or to translating devices.

Charge—The quantity of electricity that exists on the surface of an insulated electrified conductor. (See capacity.)

Choke Coil—Coil of high self-inductance, used in connection with lightning arresters and placed in series with the line to be protected.

Circuit—A circuit is a path composed of a conductor, or of several conductors joined together, through which an electric current flows from a given point around the conducting path, back again to its starting point.

Circuit, Closed—A series of conductors joined end to end so as to form an endless chain is said to be a closed circuit. (It may or may not have an electric current passing through it.)

Circuit, Grounded—A circuit in which the conductors have come into contact with the ground, or with some electric conductor leading to the ground, is said to be a grounded circuit. (See ground.)

Circuit, Multiple—A compound circuit in which a number of separate sources, or separate electro-receptive devices, or both, have all their positive poles connected to a single positive lead, or conductor, and all their negative poles to a single negative lead or conductor. (See circuit, parallel and shunt.)

Circuit, Open—A circuit, the conducting continuity of which is cut or interrupted.

Circuit, Parallel—A name sometimes applied to circuits connected in multiple. (See circuit, multiple and shunt.)

Circuit, Series—A compound circuit in which the separate sources, or the separate electro-receptive devices, or both, are so placed that the current produced in each, or passed through each, passes successively through the entire circuit from the first to the last.

Circuit, Short—See short circuit.

Circuit, Shunt—See shunt circuit.

Circular Mil—A unit of area employed in measuring the cross-section of wires; equal, approximately, to 0.7854 square mils. The area of a circle one mil (.001 inches) in diameter.

Clockwise Motion—A rotary motion whose direction is the same as that of the hands of a clock, viewed from the face.

Coefficient of Inductance—A constant quantity such that, when multiplied by the current strength passing through any coil, or circuit, will numerically represent the flux linkage with that coil or circuit due to that current. A term sometimes used for coefficient of self-induction. The ratio of the counter e. m. f. of self-induction in a coil, or circuit, to the time rate of change of the inducing current. (See inductance.)

Coefficient of Mutual Inductance—The ratio of the electromotive force induced in a circuit to the rate of change of the inducing current in a magnetically associated circuit.

Coefficient of Self-Induction—That ratio in any circuit of the flux induced by and linked with a current, to the strength of that current.

Coil, Electric—A convolution, or turn, of insulated wire through which an electric current may be passed. A number of turns of wire, or a spool of wire, through which an electric current may be passed.

Collector Rings—The metallic rings on an alternating current dynamo, or motor, which are connected to the armature wires and over which the brushes slide.

Commutator—A device for changing the direction of electric currents, usually used for changing alternating into continuous currents. (See alternating current, rectification of.)

Commutator Segments—The insulated bars composing a commutator.

Compensated Wattmeters—A wattmeter so wound as to be compensated for the effect of reactance in its potential circuit.

Components of Impedance—The energy component, or effective resistance, and the wattless component, or effective reactance.

Condenser—A device for increasing the capacity of an insulated conductor by bringing it near another earth-connected conductor, but separated therefrom by any medium that will permit electrostatic induction to take place through its mass.

Conductance—The reciprocal of resistance. $G = \frac{1}{R}$.

Conductivity, Electric—The reciprocal of electric resistivity. The conductance of a substance referred to unit dimensions.

Conductor—Any substance which will permit the so-called passage of an electric current.

Conduit, Electric—An enclosed space, either single or provided with a number of separate spaces called ducts, employed for the reception of electric wires or cables.

Connecting Sleeve—A metallic sleeve employed as a connector for readily joining the ends of two or more wires.

Consequent Pole—A magnet pole formed by two free north or two free south poles placed together. A magnet pole developed at some point of a magnet other than its extremities. .(See Figs. 15 and 16.)

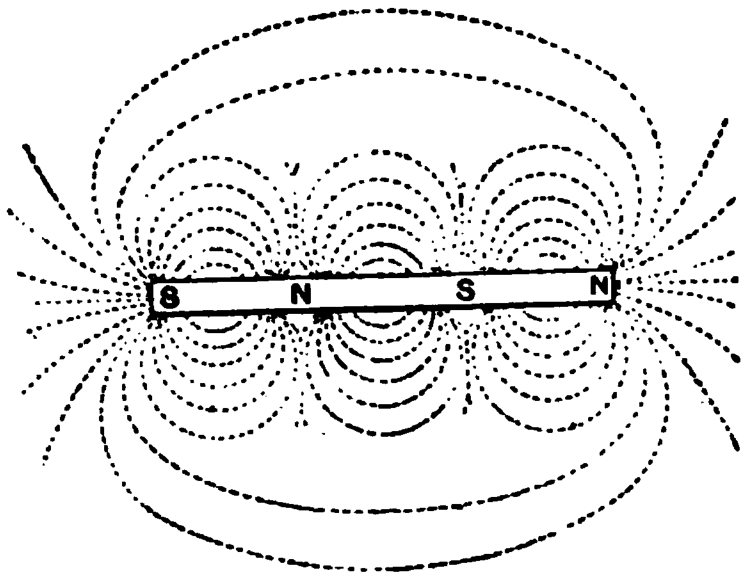


FIG. 15.—Magnet with Consequent Poles.

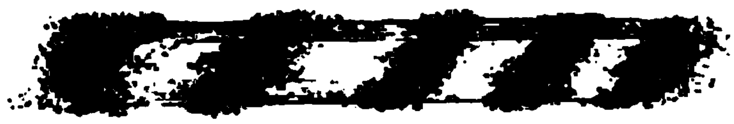


FIG. 16.—Attraction of Iron Filings by a Magnet with Consequent Poles.

If a pole of a strong magnet be gradually brought up to a like pole of a weaker magnet, repulsion will take place when they are within a certain distance of each other; but if the distance is diminished so that the two magnets are close together, attraction will result; from the fact, that the natural polarity of the weaker magnet has been reversed. This is sure to be the case whenever a weak magnetic needle is suddenly placed in a strong magnetic field, wherein the lines of force are flowing in the opposite direction to those through the needle, and the needle for some cause is not free to instantly turn round so as to set its polarity in the same direction as that of the field. Great care should therefore be taken, not to subject magnets or needles to this reversing action. In other cases, again, unlike poles, or what are termed consequent poles, may be found existing somewhere along its length, as shown in Fig. 15. In either case,

before the magnet or needle can be effectively made use of again for experimental purposes it must be freshly and properly magnetized.

Consonance, Electric—In an alternating current circuit the co-phasing of the impressed e. m. f. with the primary current, due to the influence of capacity on an inductively associated secondary circuit. A characteristic of a circuit in which the capacity and the inductance are equal and opposite in effect.

Constant—Of an electrical instrument or meter is that quantity which used as a factor with indications of instruments, or readings of a watt-hour meter register, gives results in the desired unit.

A quantity used in a formula, the value of which remains the same, regardless of the value of the other quantities used in the formula.

Converter—A secondary generator for transforming alternating into continuous currents or vice versa, consisting of an alternating current machine whose armature winding is connected with a commutator; or a continuous current machine, whose armature is tapped at symmetrical points and connected to collector rings; so that, when the armature runs it is an alternator on one side and a continuous current machine on the other. A rotary transformer.

Corrosion, Electrolytic—A term frequently employed for the corrosion of water, or gas pipes, or other masses of metal buried in the earth by electrolytic action.

Coulomb—The practical unit of electric quantity. Such a quantity of electricity as would pass in one second through a circuit conveying one International ampere.

Coulomb-meter—A meter for measuring in coulombs, the quantity of electricity which passes through any circuit.

Couple, Thermo-Electric—Two dissimilar metals which when connected at their ends only, so as to form a complete electric circuit, will produce a difference of potential, and hence an electric current, when one of the ends is heated more than the other.

Couple, Voltaic—Two materials, usually two dissimilar metals, capable of acting as a source of electricity when immersed in a[n]

electrolyte, or capable of producing a difference of electrical potential by mere contact (Fig. 17).

Cross, Electric—A connection, generally metallic, accidentally established between two conducting lines. A defect in a telegraph, telephone, electric power, or other circuit, caused by two wires coming into contact by crossing each other.

Current—This word and also the word "flow" arose from a misconceived analogy between the electric current and a current of liquid in a tube. This term will be used in its accepted sense.

The quantity of electricity per second, which passes through any conductor or circuit, when the flow is uniform. The rate at which a quantity of electricity flows or passes through a circuit. The ratio, expressed in terms of electric quantity per second, existing between the electromotive force causing a current and the resistance which opposes it.

The unit of current, or the ampere, is equal to one coulomb per second. See ampere, and coulomb.

The word current must not be confounded with the mere act of flowing; electric current signifies rate of flow, and always supposes an electromotive force to produce the current, and a resistance to oppose it.

The electric current is assumed to flow out from the positive terminal of a source, through the circuit and back into the source at the negative terminal. It is assumed to flow into the positive terminal of an electro-receptive device such as a lamp, motor, or storage battery, and out of its negative terminal; or, in other words, the positive pole of the source is always connected to the positive terminal of the electro-receptive device.

The current that flows or passes in any circuit is, in the case of a continuous current, equal to the electromotive force, or difference of potential, divided by the resistance, as:

$$I = \frac{E}{R}\ ;\ \text{for alternating current } I = \frac{E}{Z}$$

The flow of an electric current may vary in any manner whatsoever.

A current which continues flowing in the same direction no matter how its strength may vary, is called a continuous current, or sometimes a direct current, analogous to the flow of a river. If the strength of such a current is not constant, it is a varying continuous current. A regularly varying continuous current is called a pulsatory or pulsating current, analogous to the flow of blood in the veins. A current which alternately flows in opposite directions, no matter how

its strength may vary, is called an alternating current. This may be periodic or non-periodic.

Current, Alternating—See alternating current.

Current, Continuous—An electric current which flows in one and the same direction. A steady, or non-pulsating, direct current.

Current, Determination of, from Wattage Rating—The rated current may be determined as follows: If P = rating in watts, or apparent watts, if the power-factor be other than 100 per cent, and E = full-load terminal voltage, the rated current per terminal is:

$I = \frac{P}{E}$ in a continuous current, or single-phase apparatus.

$I = \frac{1}{\sqrt{3}} \frac{P}{E}$ in three-phase apparatus.

$I = \frac{1}{2} \frac{P}{E}$ in two-phase four-wire apparatus.

Current, Foucault—See Foucault.

Current Strength—In a continuous current circuit the quotient of the total electromotive force divided by the total resistance. The time-rate-of-flow in a circuit expressed in amperes, or coulombs per second. In an alternating current the quotient of the total electromotive force divided by the impedance.

Current Transformer—A stationary device for changing, by electromagnetic induction, the strength of an alternating current in one circuit to a strength of current in another in a definite ratio.

Cut-Out—A device for removing an electro-receptive device, or loop, from the circuit of an electric source. A porcelain fuse block.

Cycle—A succession of events which periodically recur, reckoning from any stage of the disturbance to the moment at which that stage next occurs. A complete recurrence of any periodic change. One complete periodic oscillation of an alternating current wave. Two alternations; 60 cycles per second equals 120 alternating per second, or 7,200 per minute.

Damping Magnet—Any magnet employed for the purpose of checking the motions of a moving body, or magnet.

Damping Suspension—A suspension which is rendered dead-beat, or aperiodic, by the application of any retarding force or dampening mechanism.

D'Arsonval Galvanometer—The class of galvanometers in which the needle, or mirror, is attached to and actuated by a small coil which is suspended by means of a fine wire between the poles of a permanent magnet. The axis of this coil is normally at right angles

with the lines of the field. Current is lead into the coil by means of the small suspension wire and leaves the coil by a flexible wire usually in the form of a helical spring attached underneath the coil.

Dead-Beat Galvanometer—An aperiodic galvanometer, or one whose needle comes quickly to rest instead of repeatedly swinging to-and-fro. A heavily damped galvanometer.

Dead Ground or Grounding—Such a grounding as will ensure a ground of negligible resistance.

Delta Connection—The connection of circuits employed in a delta three-phase system.

Delta Three-phase System—A three-phase system in which the terminal connections resemble the Greek letter delta, or a triangle.

Demand—Demand is a load specified, contracted for or used, expressed in terms of power.

Demand Factor—Unless otherwise specified, demand factor shall be the maximum connected kilowatts of capacity divided into the actual kilowatts of demand, and expressed in terms of per cent. See maximum demand. See instantaneous peak.

Density of Current—The quantity of current that passes per unit of area of cross section in any part of a circuit.

Density of Field—The quantity of magnetic flux that passes through any field per unit of area of cross section.

Detector Galvanometer—Any rough form of galvanometer, or galvanoscope, employed for detecting the presence of electric currents.

Diamagnetic—The property possessed by substances like bismuth, phosphorus, antimony, zinc and others, of being apparently repelled when placed between the poles of powerful magnets.

Dielectric—Any substance which permits electrostatic induction to take place through its mass.

The substance which separates the opposite coatings of a condenser is called the dielectric. All dielectrics are non-conductors.

All non-conductors, or insulators, are dielectrics but their dielectric power is not exactly proportional to their non-conductive power.

Substances differ greatly in the degree or extent to which they permit induction to take place through or across them. Thus, a certain amount of inductive action takes place between the insulated metal plates of a condenser across the layer of air between them.

A dielectric may be regarded as pervious to rapidly reversed periodic currents, but opaque to continuous currents. There is, however, some slight conduction of continuous currents.

Dielectric Capacity—A term employed in the same sense as specific inductive capacity.

Dielectric Hysteresis—A variety of molecular friction, analogous to magnetic hysteresis produced in a dielectric under charges of electrostatic stress. That property of a dielectric by virtue of which energy is consumed in reversals of electrification.

Dielectric Strain—The strained condition of glass or other dielectric of a condenser produced by the charging of the condenser. The deformation of a dielectric under the influence of an electromagnetic stress.

Differential Galvanometer—A galvanometer containing two coils, so wound as to tend to deflect its needle in opposite directions.

Dipping Magnetic Needle—A magnetic needle suspended so as to be free to move in a vertical plane only, and employed to determine the angle of dip or magnetic inclination. An inclination compass.

Direct Current—A current whose direction is constant, as distinguished from an alternating current. A unidirectional current. It embraces both pulsating and continuous current. Erroneously applied to continuous current only.

Drop—A word frequently used for drop of potential, or electromotive force. The fall of potential which takes place in an active conductor.

Drum Armature—An armature whose coils are wound longitudinally over the surface of a cylinder or drum.

Dry Voltaic Cell—A misnomer for a voltaic cell in which the fluid electrolyte is held in suspension by sawdust, gelatine, or other suitable material. A sealed voltaic cell, which can, therefore, be inverted without danger of spilling liquid.

Dynamic Electricity, Electrodynamics—A term sometimes employed for current electricity, in contradistinction to static electricity.

Dynamo—A rotating machine for the conversion of mechanical energy into continuous current electrical energy by means of electric dynamic induction.

Earth Plates, Ground Plates—Plates of metal, buried in the earth or in water arranged to be connected to electric wires for the purpose of grounding the circuit.

Earth Return—That portion of a grounded circuit in which the earth forms a conducting path.

Earth's Field—The magnetic field produced in any place by the earth's flux.

Earth's Flux—The magnetic flux produced by the earth by virtue of its magnetized condition.

Eddy Current—Currents produced in the pole-pieces, armature, and field magnet cores of dynamos, or motors, or in metallic masses

generally, by either their motion, through magnetic flux, or by variations in the strength of electric currents flowing near them.

Effective Value—The square root of the mean squared value of any harmonic wave is called the effective value of that wave. When the graph of the wave is drawn the effective value can be determined by applying the above definition. Example: Divide one-half of the cycle into ten equal parts, square the ordinates which bisect the lengths of the abscissæ between the chosen points, and by extracting the square root of the average of the squared values the effective value is found. For sinusoidal waves the above computation is not necessary, since the effective value may be found by dividing the maximum value by the square root of two. The proof of this is as follows:

Let Oa, Fig. 18, represent the maximum value of the sine wave.

$$\text{Now } \sin\alpha = \frac{ab}{Oa} \text{ by definition.}$$

$$\text{Squaring, } \sin^2\alpha = \frac{ab^2}{Oa^2}.$$

$$\text{Also } \cos\alpha = \frac{Ob}{Oa} \text{ by definition.}$$

$$\text{Squaring, } \cos^2\alpha = \frac{Ob^2}{Oa^2}$$

By elementary principles of trigonometry,

$$\sin^2\alpha + \cos^2\alpha = 1 \ldots\ldots\ldots\ldots\ldots (1)$$

Substituting in (1)

$$\frac{ab^2}{Oa^2} + \frac{Ob^2}{Oa^2} = \frac{ab^2 + Ob^2}{Oa^2} = \frac{Oa^2}{Oa^2} = 1$$

Since the line Oa revolves, thus generating the sine wave, the sine varies from O to Oa and the cosine varies from Oc = Oa to O, so that the sine and cosine pass through the same values and therefore the average of the squares of the sine and cosine must be equal.

Hence, since $\sin^2\alpha + \cos^2\alpha = 1$

also $\text{av. } \sin^2\alpha + \text{av. } \cos^2\alpha = 1$

then must

$$2 \text{ av. } \sin^2\alpha = 1$$

or

$$\text{av. } \sin^2\alpha = \tfrac{1}{2}$$

that is,

$$\sqrt{\text{av. }\sin^2 \alpha} = \frac{1}{\sqrt{2}} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

By definition of an alternating e. m. f. wave (alternating sine wave)

$$e = E \sin \alpha$$

or

$$e^2 = E^2 \sin^2 \alpha$$

or

$$\text{av. } e^2 = E^2 \text{ av. } \sin^2 \alpha \ldots\ldots\ldots\ldots\ldots (3)$$

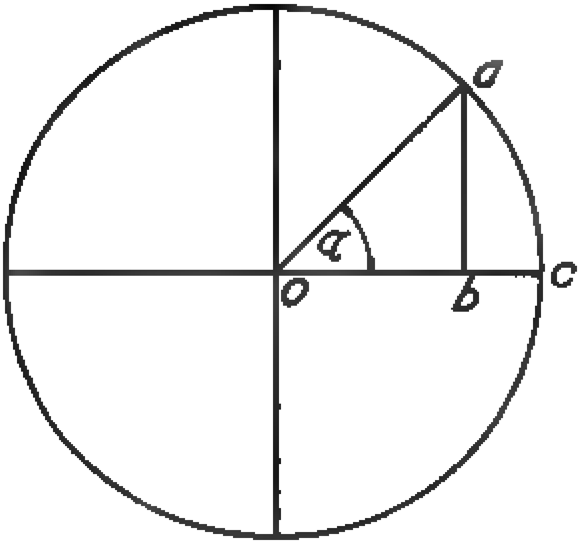


FIG. 18.—Diagram for Determining the Effective Value.

FIG. 19.—Illustration of Relation of Average and Maximum Sinusoidal e.m.fs.

Substituting (2) in (3)

$$\text{av. } e^2 = \frac{E^2}{2}$$

or

$$\sqrt{\text{av. } e^2} = \frac{E}{\sqrt{2}} = .707\, E$$

that is, the effective or square-root-of-mean-square value is equal to the maximum value multiplied by $\frac{1}{\sqrt{2}}$ or .707.

In the same way it can be shown that if E is the maximum value, the average value is $\frac{2E}{\pi}$ or .636 E. Diagrammatically this is shown in Fig. 19.

For sine waves the effective value = 1.11, multiplied by the average value.

Electricity Meter—An apparatus used for the purpose of measuring the quantity of electricity. Attention is called to the difference between "meter" and "instrument." The latter term is used to designate that type of apparatus which indicates, i. e., a meter measures and an instrument indicates.

Electrification—The production of an electric charge.

Electrochemical—Of or pertaining to, electrochemistry.

Electrochemistry—That branch of electrical science which treats of chemical combinations and decompositions effected by the electric current. The science which treats of the relation between the laws of electricity and chemistry.

Electrode—Either of the terminals of an electric source. Either of the terminals of an electric source that are placed in a solution in which electrolysis is taking place.

Electrolysis—Chemical decomposition effected by means of an electric current. The decomposition of the molecule of an electrolyte into its ions or radicals. Electrolytic decomposition.

Electrolyte—Any compound liquid which is separable into its constituent ions or radicals by the passage of electricity through it. The exciting liquid in a voltaic cell.

Electromagnet—A mass of iron which is magnetized by current through a coil of wire wound around the mass but insulated therefrom.

Electromagnetic Units—A system of CGS units employed in electromagnet measurements. Units based on the attraction and repulsions capable of being exerted between two unit magnetic poles at unit distance apart, or between a unit magnetic pole and a unit electric current.

Electrometer—An apparatus for measuring differences of electric potential or voltage.

Electron—A word formerly used for amber. The electric atoms whose projection from the cathode of a high-vacuum tube is supposed to constitute the cathode rays or streamings.

Electroscope—An apparatus for showing the presence of an electric charge, or determining its character, whether positive or negative, but not for measuring its amount or value.

Electrostatic Capacity—The quantity of electricity which must be imparted to a given conductor as a charge, in order to raise its potential to unity, all neighboring conductors being at zero potential.

Electrostatic Field—Lines of force produced in the neighborhood of a charged body, by the presence of the charge. Lines extending in the direction in which the force of electrostatic attraction or repulsion acts.

Electrostatic Potential—The power of doing electric work possessed by a unit quantity of positive electricity residing on the surface of an insulated body. That property in space by virtue of which work is done when an electric charge is moved therein.

Energy Component of Current—In an alternating current circuit, the component of current which is in phase with the impressed e. m. f. In an alternating current circuit, the product of the e. m. f. and the effective conductance.

Energy Component of e. m. f.—In an alternating current circuit the component of e. m. f. which is in phase with the current. In an alternating current circuit, the product of the e. m. f. and the effective resistance.

Farad—The practical unit of electric capacity. Such a capacity of a conductor, or condenser, that one International coulomb of electricity is required to produce therein a difference of potential of one International volt.

Faraday's Experiments—The experiments on induced currents made by Faraday were the following: A coil of wire forms a closed

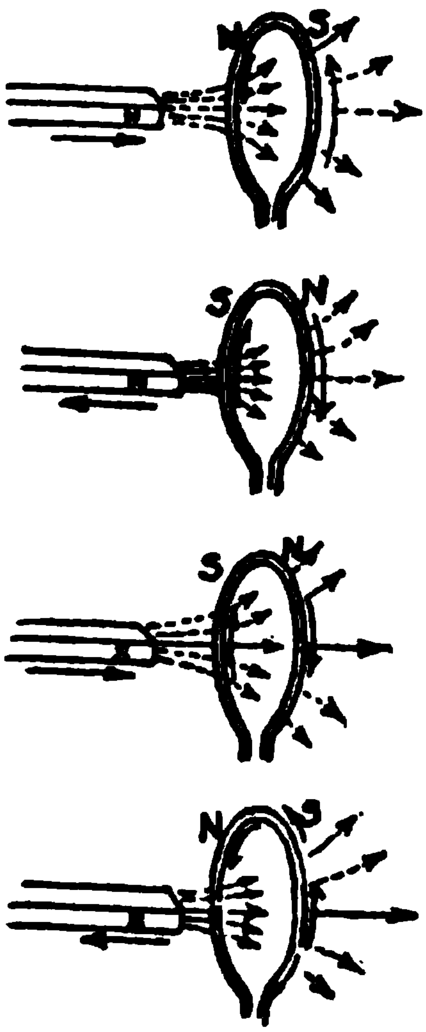


FIG. 20.—Faraday's Experiments on Induced Currents.

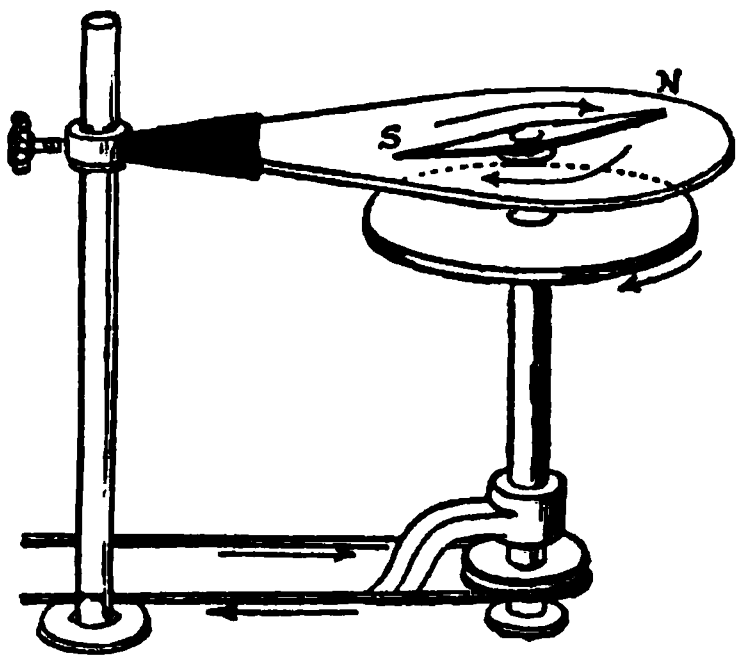


FIG. 21.—Arago's Rotation Experiment.

circuit through a sensitive galvanometer. When the pole of a magnet is brought up to the end of the coil, a momentary current is induced in the coil, and the galvanometer needle is deflected. When the magnet pole

is removed, a momentary current is again induced, but in the opposite direction to that upon approach. The following facts may be noted: (a) The essential motion is relative, that is, moving the coil to or from the magnet produces the same effect as moving the magnet; (b) the current lasts only during the time of motion; when the magnet and coil are relatively at rest, there is no induced current; (c) bringing up a north pole to a coil induces a current anti-clockwise as seen from the pole; that is, the induced current makes this face a north face. Thus the approaching north pole is repelled by the magnetic action of the induced current. Removing the north pole induces a clockwise current, that is, makes the coil face a south face. Thus the north pole is attracted as it is removed. An approaching south pole induces a current in the same direction as a receding north pole, and vice versa. Or in general the magnetic action of the induced current opposes the motion of the magnet. This is evidently a case of action and reaction. If the approaching magnet were attracted by the induced current, it would require no work to bring the magnet up, and an electric current, which represents energy, would be generated, without the expenditure of work (Fig. 20).

Field—A term sometimes used for a magnetic field. A term sometimes used for electrostatic field.

Field, Electrostatic—The region of electrostatic influence surrounding a charged body.

Field, Magnetic—The region of magnetic influence surrounding the poles of a magnet.

Field Magnets—The magnets which produce the magnetic field, or flux, in which the armature of a dynamo, motor, or meter rotates.

Field of Force—The space traversed by electrostatic or magnetic flux. An electrostatic or magnetic field.

Flux Density—The quantity of flux per unit of area per normal cross-section.

Foucault or Eddy Currents—It was observed a number of years before Faraday's discovery of induced currents, that a vibrating magnetic needle quickly came to rest when near or over a copper plate. Arago had in 1824 also shown that a magnetic needle suspended over a rotating copper disk rotates with the disk (Fig. 21). Both the damping of the needle and Arago's disk experiment were explained by Faraday as phenomena of electromagnetic induction. The relative motion of the magnet and the disk induces an e. m. f. in the metal disk. The current thus generated circulates in the disk, producing a magnetic action, which by Lenz's law tends to hold the magnet at rest relative to the disk or plate.

Electric currents, thus induced and circulating in a metallic mass, are

called eddy currents or Foucault currents. The energy of such currents is dissipated in heat. The iron cores of armatures of dynamo machines and transformers are always laminated so as to offer infinite resistance

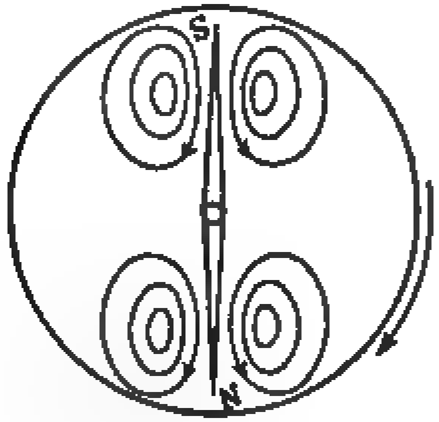


FIG. 22.—Foucault Currents Generated in Disk by Arago's Rotation.

FIG. 23.—Another Form of Arago's Experiment.

to the formation of such currents, and thus to stop the heat losses (Figs. 22 and 23).

Frequency of Alternation—The number of cycles or periods executed by an alternating current in unit time. The periodicity. The two standard frequencies are now 25 and 60 cycles per second.

Frictional Electricity—The electricity developed by friction.

Fundamental Frequency—The nominal or lowest frequency of a complex harmonic electromotive force, flux or current.

Fundamental Units—The units of length, time and mass, to which all other quantities can be referred. Units of length, time and mass, as distinguished from their derivations or derived units. The fundamental electrical units are the volt, ampere and ohm.

Fuse, Electric—A conductor designed to melt or fuse at a certain value of current and time and by so doing to rupture the circuit.

Galvanometer—An apparatus for measuring the strength of an electric current by the deflection of a magnetic needle. A current measurer.

The galvanometer depends for its operation upon the fact that a conductor, through which an electric current is flowing, will deflect a magnetic needle placed near it. This deflection is due to the magnetic field caused by the current.

The needle is deflected by the current from a position of rest, either in the earth's magnetic field or in a field obtained from a permanent or electromagnet. In the first case, when in use to measure a current, the plane of the galvanometer coils must coincide with the planes of the mag-

netic meridian. In the other case, the instrument may be used in any position in which the needle is free to move.

Galvanometers assume a variety of forms according either to the purposes for which they are employed, or to the manner in which their

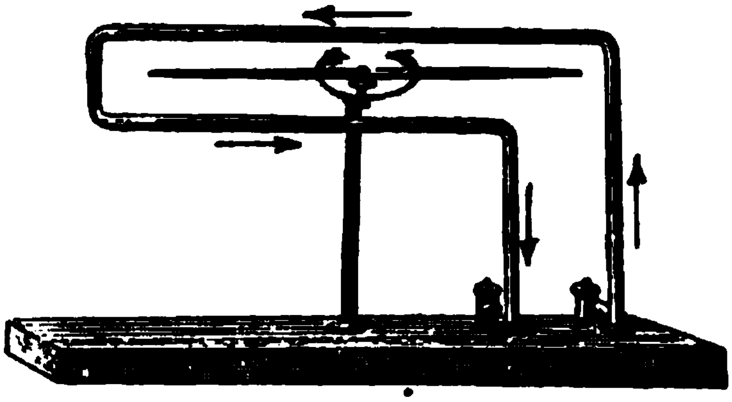


FIG. 24.—Oersted's Single-turn Galvanometer.

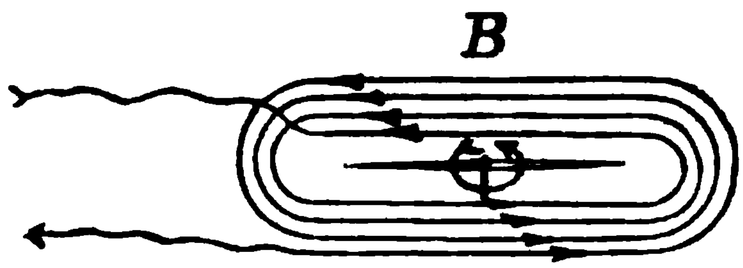


FIG. 25.—Diagram showing Augmented Action by Multiplication of Turns.

deflections are valued (Figs. 24 and 25). (See astatic galvanometer and ammeter).

Galvanometer Constant—The constant of calibration of the galvanometer scale. The numerical factor connecting a current passing through a galvanometer with the deflection produced by such current. The value of one division of the galvanometer scale in terms of current strength.

Galvanometer Shunt—A shunt placed around a sensitive galvanoeter in order to protect it from the effects of a strong current, or for reducing its sensibility.

Galvanoscope—A galvanometer intending to show the existence of a current rather than to measure its strength. A crude or simple form of galvanometer.

Gauss—The name proposed in 1894 by the American Institute of Electrical Engineers for the c.g.s. unit of magnetic flux density. A unit of intensity of magnetic flux, equal to one c.g.s. unit of magnetic flux per square centimeter of area of normal cross section. A name proposed for the c.g.s. unit of magnetic potential or magnetomotive force by the British Association in 1895.

Generator—A dynamoelectric machine. One which transforms mechanical into electrical power. (See Alternator; see Dynamo.)

Gilbert—A name proposed for the c.g.s. unit of magneto motive force. A unit of magnetomotive force equal to that produced by $\frac{1}{1.2566}$ of one ampere-turn.

Gradient, Electric—The rapidity of increase or decrease of the strength of an electromotive force or current.

Gram—A unit of mass equal to 15.43235 grains. The mass of a cubic centimeter of water at the temperature of its maximum density.

Ground—A general term for the connection of a conductor to the earth.

Ground, Effect of—On neutral point of three-phase, three-wire system.

Consider a general case. A lightning stroke disables some apparatus so that inductive reactance is introduced in the accidental ground. Before the accident there was a perfectly balanced system, where the neutral, or ground potential, is symmetrical in reference to the line conductors

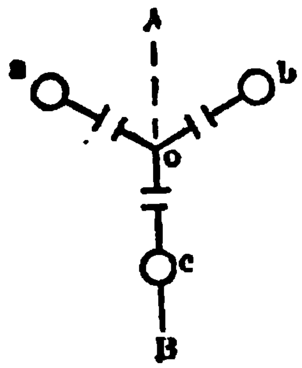


Fig. 26.

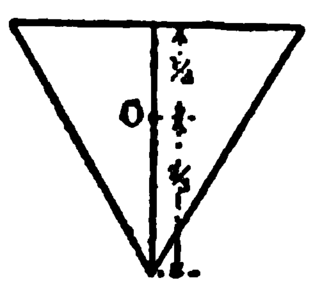


Fig. 27.

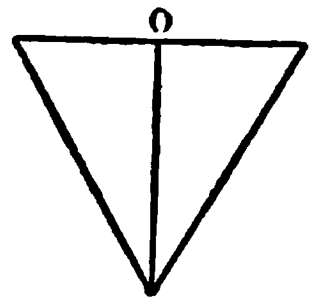


Fig. 28.

and governed entirely by the ground capacities represented in Fig. 26 as three condensers. If, now, one line is grounded through an impedance, the neutral will be displaced along line AB.

The conditions are then:

First. Ground made by infinite reactance. (No ground.) We have then $x = \infty$, $e_1 = \frac{2}{3e}$ and $e_2 = \frac{1}{3e}$ when e_1 is the voltage from one wire to the neutral of a balanced system and e_2 is the voltage from the neutral of the balanced system to a point midway between the other two wires and x is the condensive reactance; that is, in Fig. 27, the neutral lies at O, and the ground is symmetrical in reference to the three lines.

Second, when $e_2 = O$, and $e_1 = e$ (shown in Fig. 28).

In this case the neutral lies midway between the other two conductors, and its potential difference to ground is .87e.

Third, when e_1 and e_2 both become infinite, under such condition, the system would be subjected to infinite potential.

The third condition arises if one line is grounded by a reactance of ⅓ of the condensive reactance, the system then being subjected to very great stresses, even at normal frequency.

Ground Circuit—A circuit in which the ground forms part of the path through which the current passes.

Ground-return—A general term used to indicate the use of the ground, or earth, for part of an electric circuit. The earth, or ground, which forms part of the return path of an electric circuit.

Ground-wire—The wire, or conductor, leading to, or connected with, the ground, or earth, in a grounded circuit.

Harmonic Currents—Periodically alternating currents varying harmonically. Currents which are harmonic functions of time. Sinusoidal currents.

In modern alternators an endeavor is made to shape the magnetic circuit so that the e. m. f. is a sine wave, nevertheless, a triple harmonic of some magnitude usually exists in the e. m. f. wave of single-phase alternators, and in each of the individual phases of a polyphase generator. The e. m. f. between two terminals of a three-phase generator does, however, not contain any triple harmonic for the following reasons: Con-

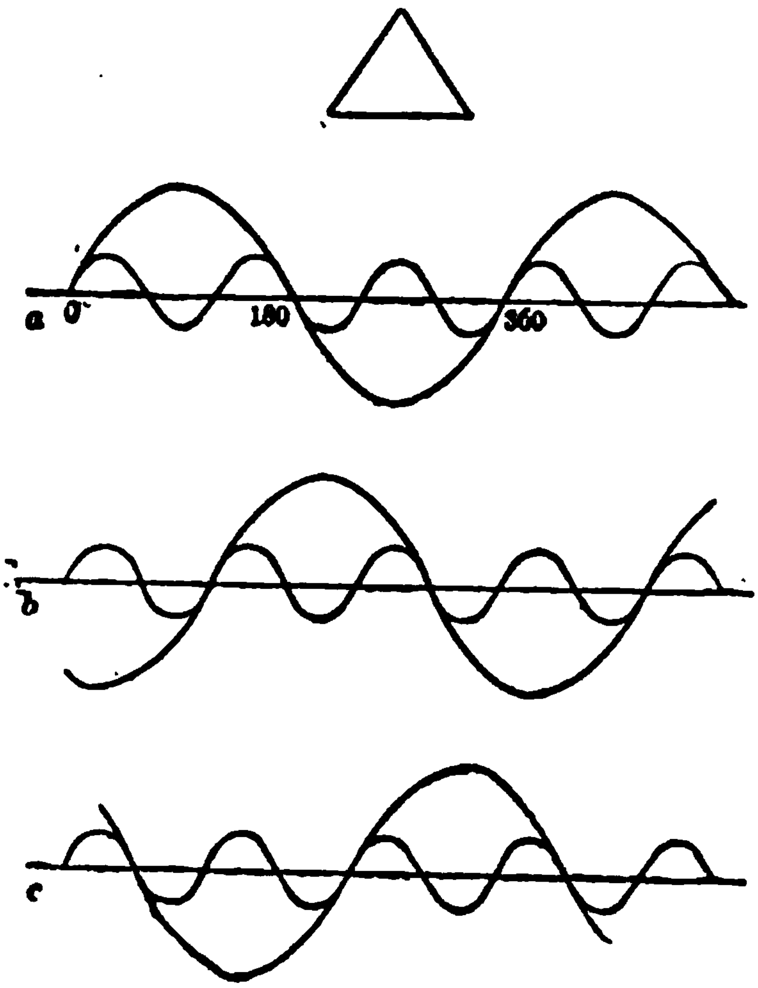


FIG. 29.—Relations of the Fundamental e.m.f. and Triple Harmonics in a Delta Connected Circuit.

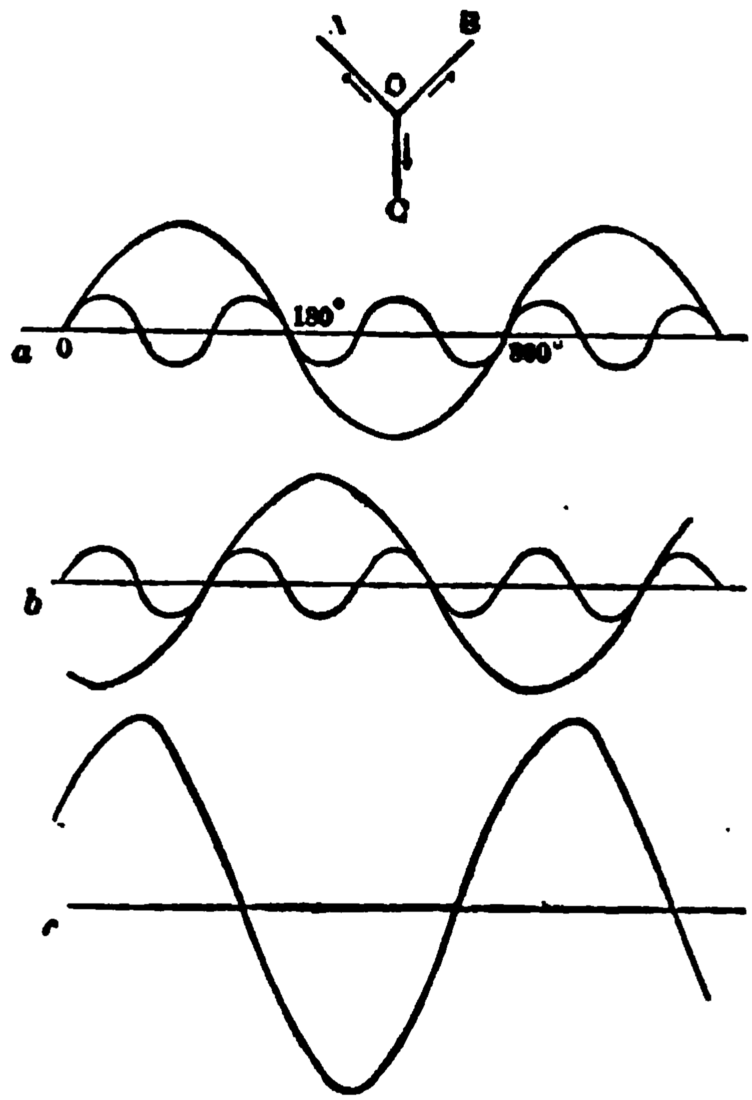


FIG. 30.—Relation of the Fundamental e.m.f. and Triple Harmonics in a Star Connected Circuit.

sider first in Fig. 29 a delta-connected three-phase generator, in each phase of which is a prominent triple harmonic; *a*, *b* and *c* represent the three e. m. fs. as displaced 120 degrees. It is seen that the three triple

harmonics are in phase, thus the machine is really running under short circuit as far as the triple harmonic is concerned. A triple frequency

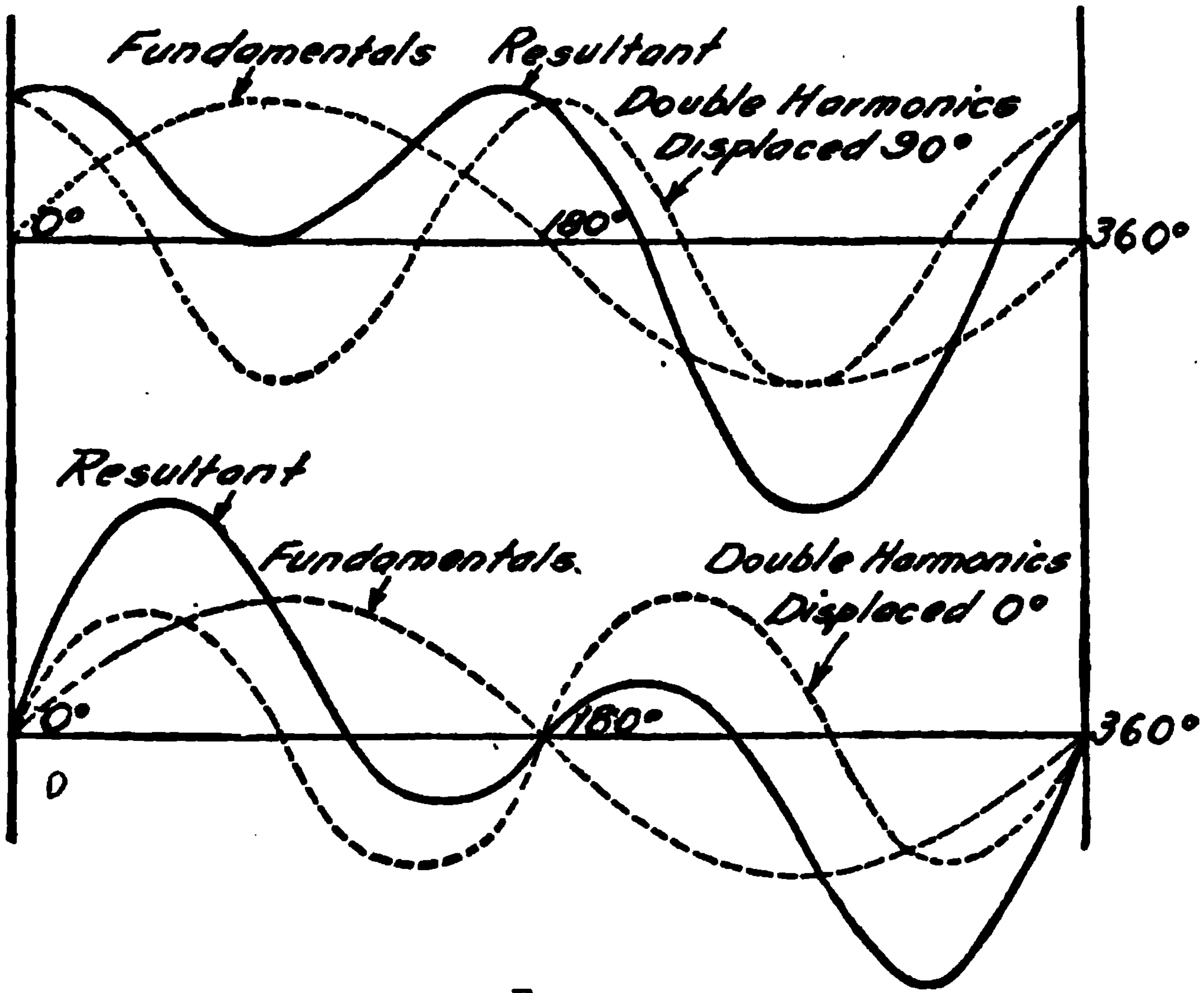


FIG. 31.

current will be established, which will consume the e. m. f., which, therefore, will not appear in the terminal e. m. f.

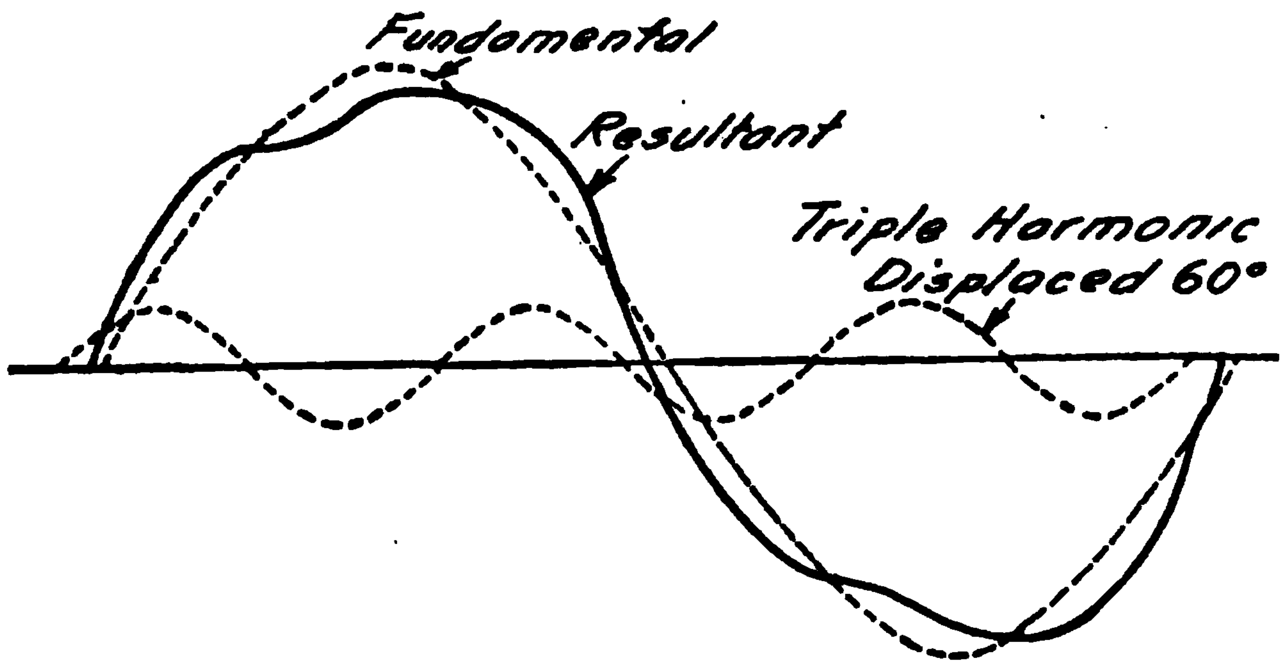


FIG. 32.

The triple harmonic current will, however, set up an armature reaction which will distort the field magnetism and thereby cause a fifth and

seventh harmonic. With star connection the terminal e.m.f. is the resultant of two e. m. fs., *OA* and *OB* in Fig. 30. Referring to Fig. 30, we see that again *OA*, *OB* and *OC*, the individual e. m. fs., are displaced 120 degrees. The e. m. f. between *A* and *B* is the resultant *OA* and *OB*, thus *OA-OB* (the minus sign on account of the direction). In *a* are given the e. m. fs. in *OA*, in *b* are given the e. m. fs. of *OB*; and their resultant (with *OB* reversed) is *c*. The triple harmonic again has disappeared, but the fundamental is larger than in the individual phases. In the e. m. f. against the neutral or ground the triple harmonic exists; therefore, the charging current against ground will be of triple fre-

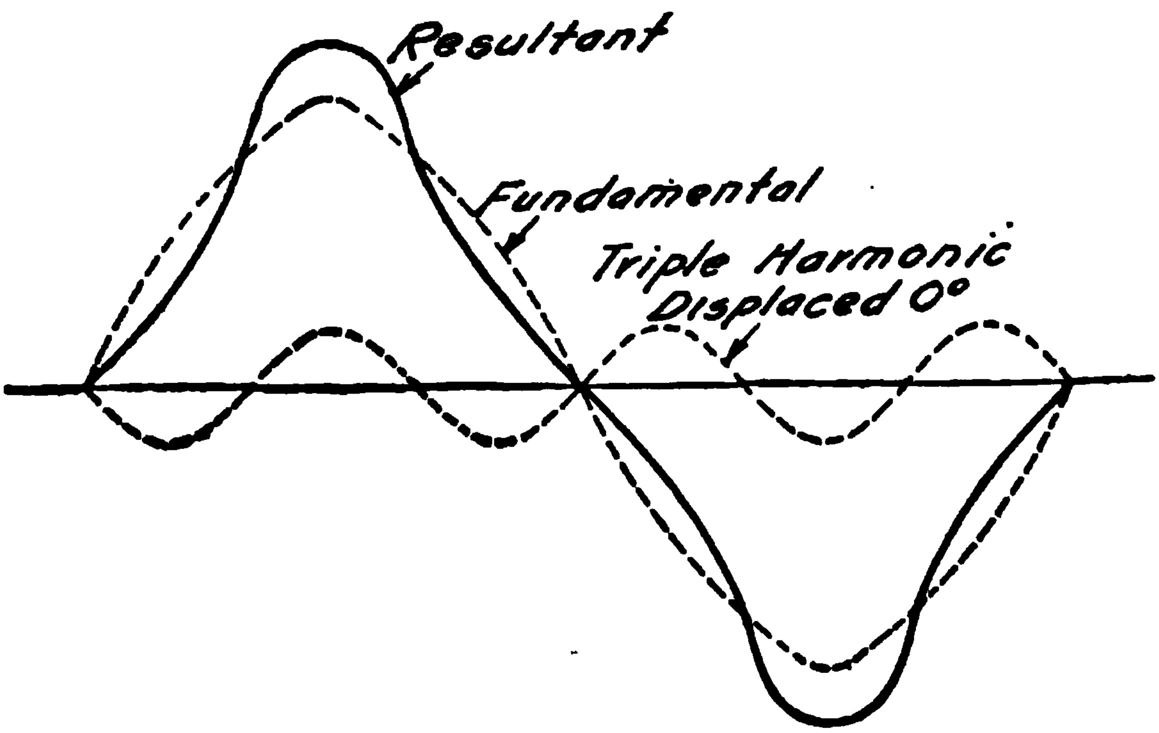


FIG. 33.

quency and any multiple thereof, if permitted to exist, that is, if the generator neutral is grounded.

The transformers are a source of triple harmonics e. m. f. or current, but this can also be eliminated if one side of the transformers is delta-connected, as should always be the case.

In general, it can be said that the triple harmonics should give no difficulties in a three-phase transmission; it need not exist.

Harmonics, Effects of Higher—To elucidate the variation in the shape of alternating waves caused by various harmonics, in Fig. 31, Fig. 32. Fig. 33 and Fig. 34 are shown the wave forms produced by the superimposition of the double, triple and the quintuple harmonic upon the fundamental sine wave.

In Fig. 35 is shown the fundamental sine wave and the complex waves produced by the superimposition of a triple harmonic of 30 per cent the amplitude of the fundamental, under the relative phase displacements of 0, 45, 90, 135 and 180 degrees.

As seen, the effect of the triple harmonic is in the first figure to flatten the zero values and point the maximum values of the wave, giving what is called a peaked wave. With increasing phase displacement of the triple harmonic, the flat zero rises and gradually changes to a second peak, giving ultimately a flat-top or even double-peaked wave with sharp zero. The intermediate positions represent what is called a saw-tooth wave.

The quintuple harmonic causes a flat-topped or even double-peaked wave with flat zero. With increasing phase displacement, the wave becomes of

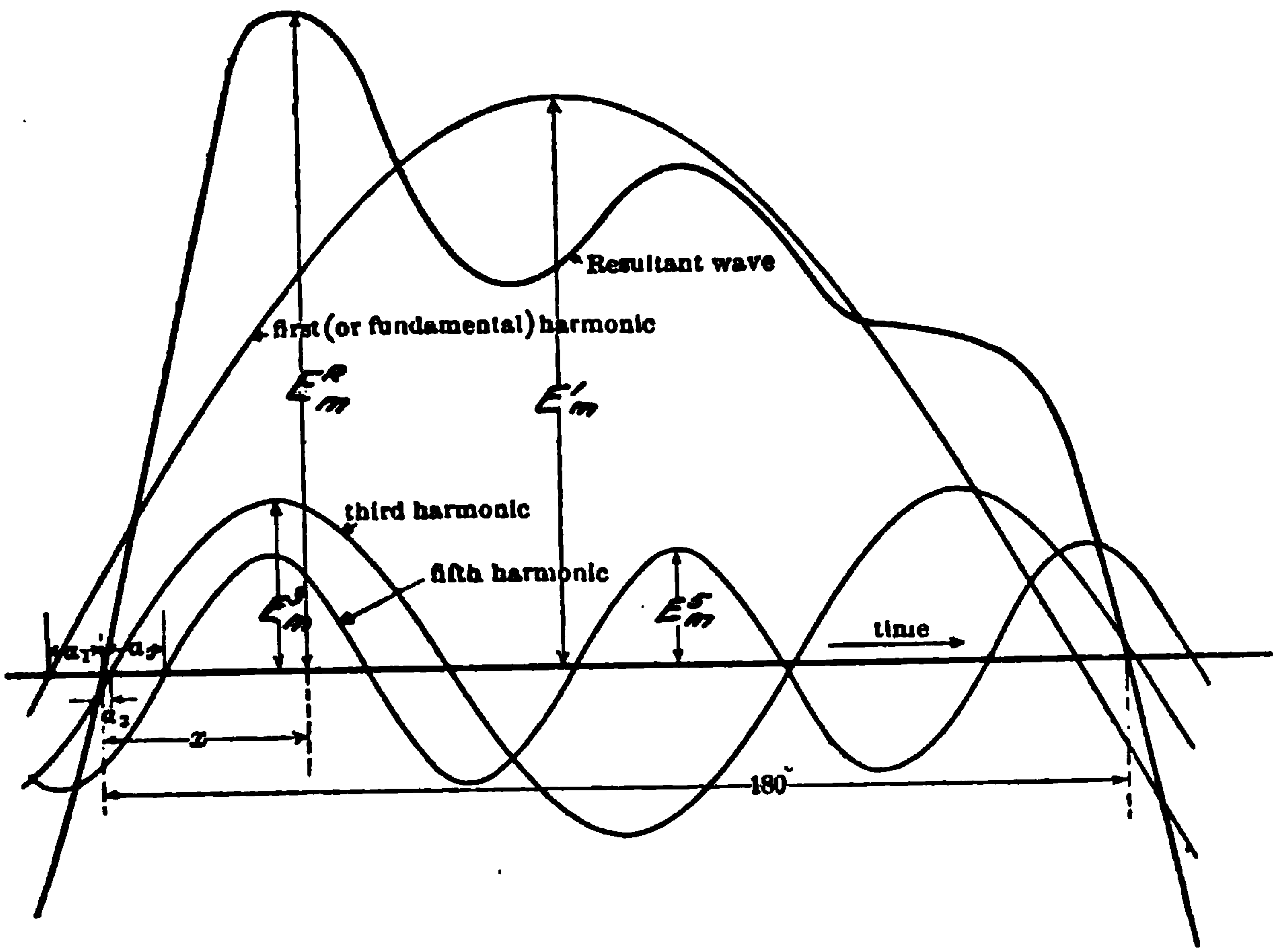


Fig. 34.

the type called saw-tooth wave also. The flat zero rises and becomes a third peak, while of the two former peaks, one rises, the other decreases, and the wave gradually changes to a triple-peaked wave with one main peak, and a sharp zero.

As seen, with the triple harmonic, flat-top or double-peak coincides with sharp zero, while the quintuple harmonic flat-top or double-peak coincides with flat zero.

Sharp peak coincides with flat zero in the triple, with sharp zero in the quintuple harmonic. With the triple harmonic, the saw-tooth shape

appearing in case of a phase difference between the fundamental and harmonic is single, while with the quintuple harmonic it is double.

Thus in general, from simple inspection of the wave shape, the existence of these first harmonics can be discovered. Some characteristic shapes are shown in Fig. 36.

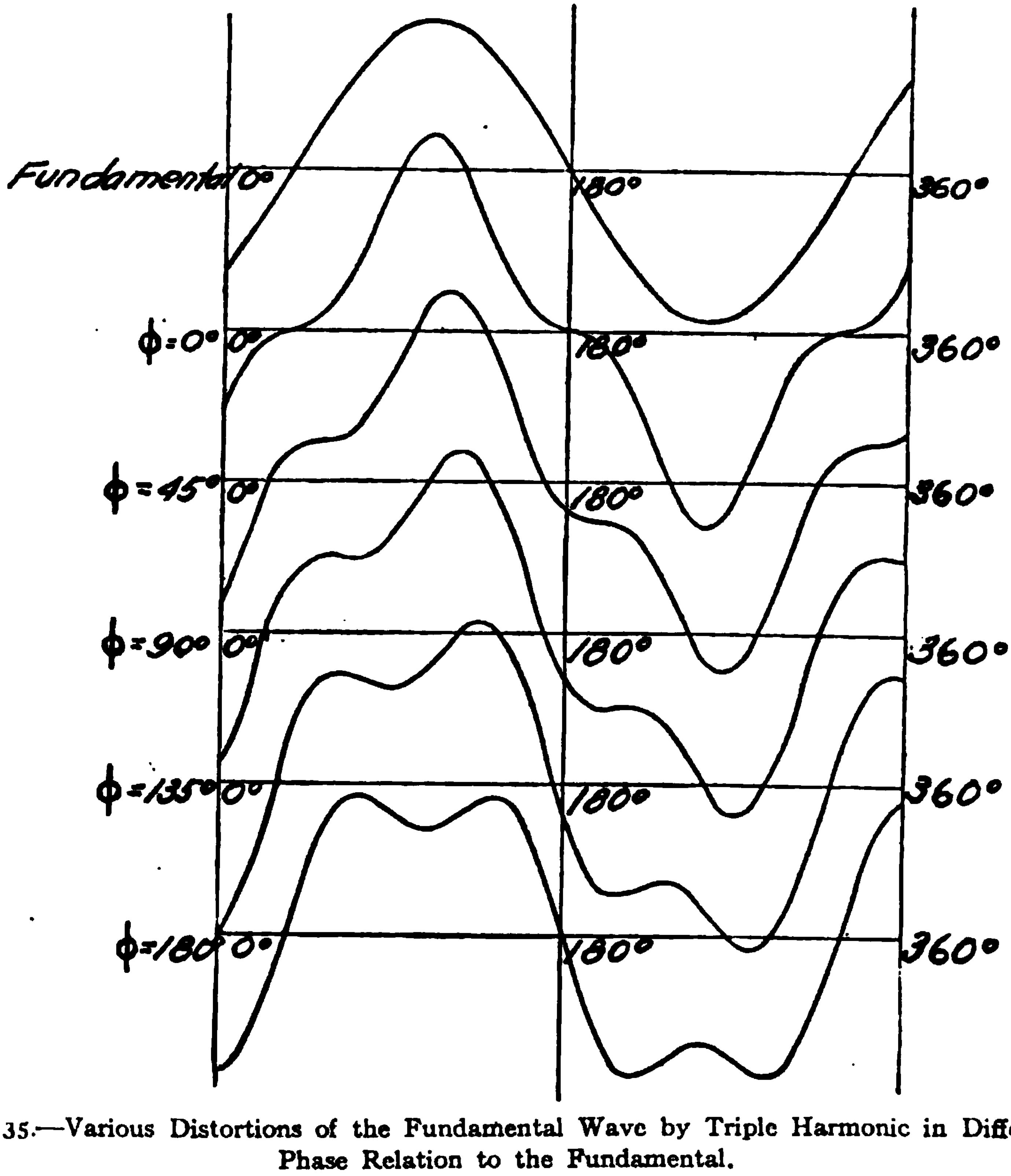


FIG. 35.—Various Distortions of the Fundamental Wave by Triple Harmonic in Different Phase Relation to the Fundamental.

Henry—The practical unit of self-induction. An earth-quadrant, or 10 centimeters.

The value of the henry as adopted by the International Electrical Congress of 1893, at Chicago, is that value of the induction in a circuit, when the electromotive force induced in the circuit is one International volt, and the inducing current varies at the rate of one ampere per second.

Horse Power—A commercial unit of power, activity, or rate of doing work. A rate of doing work equal to 33,000 pounds raised

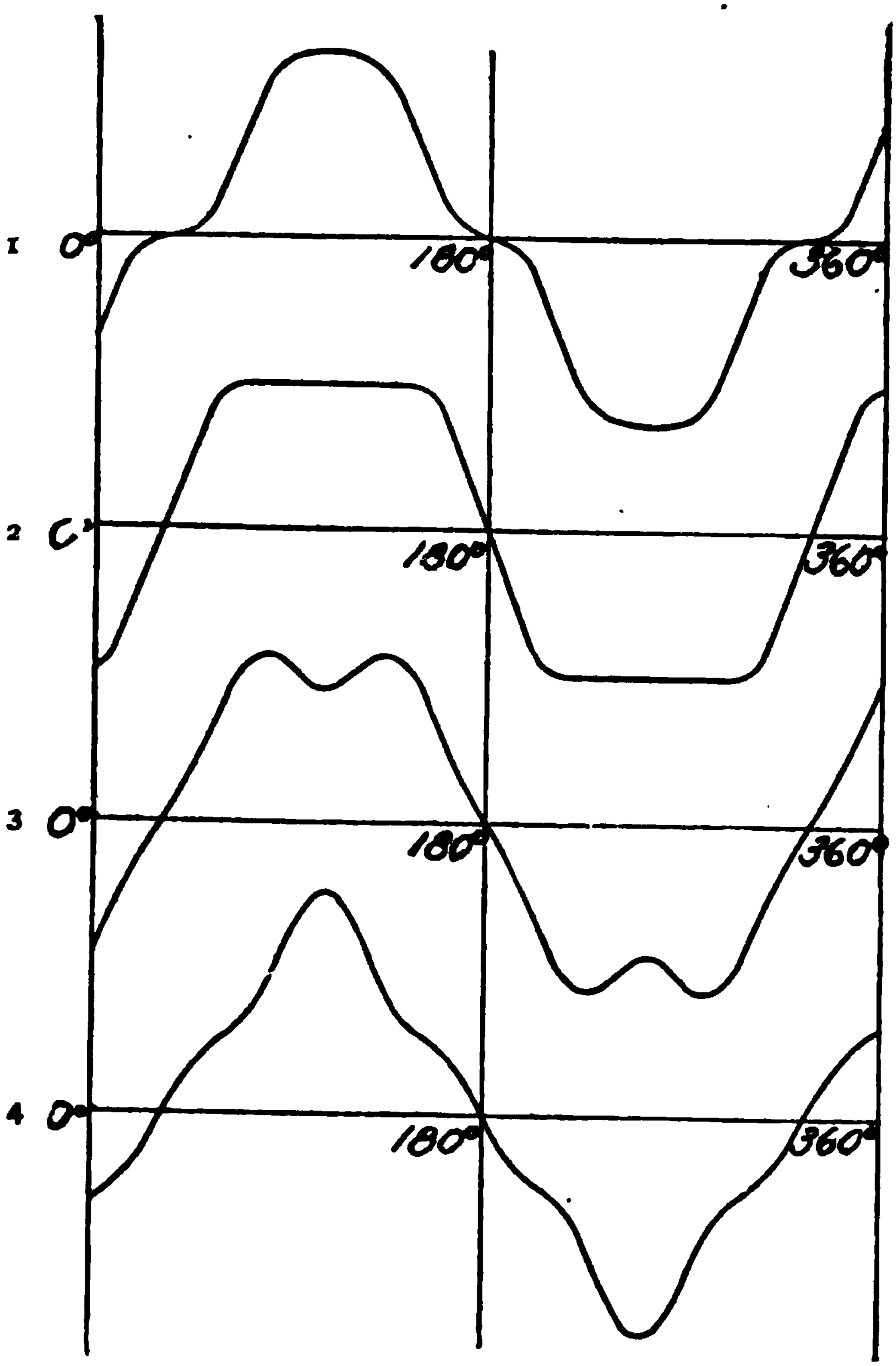


Fig. 36.—Various Distortions of the Fundamental Wave by Triple and Quintuple Harmonics of Characteristics given Below:

1. 15%	3rd, Φ = 0	10%	5th, Φ = 0
2. 22½%	3rd, Φ = 180	5%	5th, Φ = 180
3. 15%	3rd, Φ = 180	10%	5th, Φ = 0
4. 15%	3rd, Φ = 0	10%	5th, Φ = 180

one foot per minute, or 550 pounds raised one foot per second. A rate of doing work equal to 4,562 kilograms raised one meter per minute. Such a rate of doing electrical work as is equal to 746

watts, or 746 volt-coulombs per second. The horse power-hour is a unit of work equal to the work done by one horse power acting for an hours = 1,980,000 foot-pounds.

The horse power and horse power-hour are equal to 746 watts and watt-hours, respectively. Based on this relation, the horse power may be said to be approximately $\frac{3}{4}$ of a kilowatt, or conversely, a kilowatt is equal to approximately $1\frac{1}{3}$ horse power.

Hot Wire Measuring Instrument—The expansion of a conductor, owing to the heating effect of an electric current passed through it, is

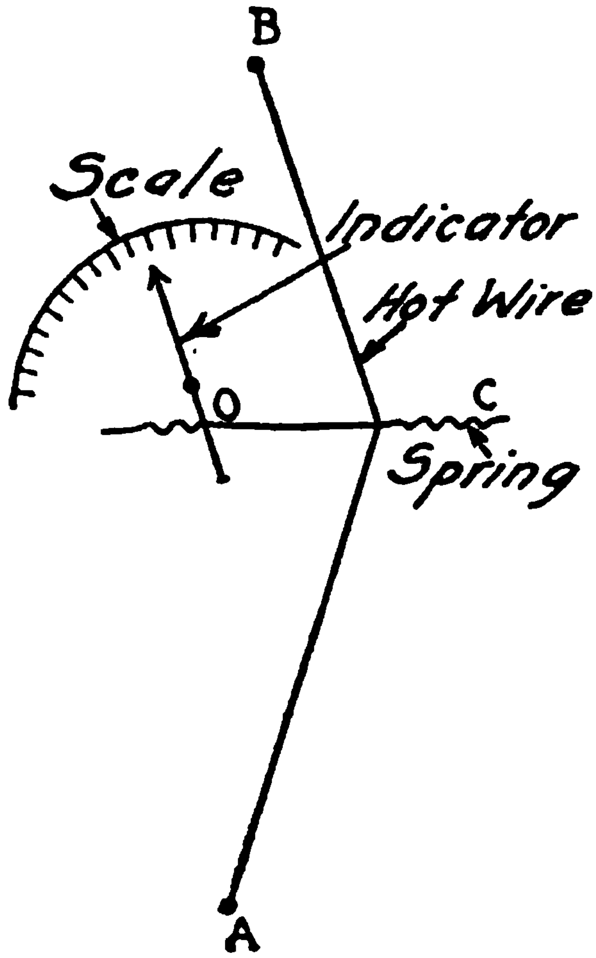


FIG. 37.—Hot-wire Type of Indicating Instrument.

made use of in some instruments to measure current strength. Suppose, for example, between the points *A* and *B* in an instrument, Fig. 37, a fine wire is fastened of such a length as to equal *AB* when quite cold. At the middle of the wire *O* is fixed a light thread extending in both directions perpendicular to the wire. On one side it is drawn taut by a spring fixed at *C*. In the other direction the thread is passed a couple of times around a small drum, to which is attached an indicator moving over a graduated scale, and is then attached to another spring of somewhat less tension than the former. From the description the action is clear. If a current passes, the wire is heated and expands, the slack being taken up by the spring *OC*. The motion of *O* will cause the drum and indicator to rotate, the amplitude of the motion depending on the rise

in temperature caused by the current. If there were no losses this would depend on the square of current strength. In practice, however, the scale is empirically graduated by the comparison of the instrument with a standard. As in this instrument the resistance is often very high, owing to the fineness of the wire, it is usually designed as a voltmeter rather than as an ammeter.

Hysteresis—A lagging behind of magnetization relatively to magnetizing force. Apparent molecular friction due to magnetic change of stress. A retardization of the magnetizing or demagnetizing effects as regards the causes which produce them. The quality of a paramagnetic substance by virtue of which energy is dissipated on the reversal of its magnetization.

Hysteretic Lag—The lag in the magnetization of a transformer due to hysteresis.

Impedance—Generally, opposition to current flow. In a simple-harmonic current circuit the square root of the sum of the squares of the resistance and reactance. The apparent resistance of a circuit containing both resistance and reactance. (See Alternating Currents.)

Impedance Circuit—A circuit containing impedance.

Impedance Coil—An inductance, reactance, or choking coil. A coil placed in a circuit, for the purpose of preventing an impulsive current rush in that circuit, by means of the counter-electromotive force developed in the coil on being magnetized.

Impressed Electromotive Force—The electromotive force brought to act in any circuit to produce a current therein. An applied e. m. f. as distinguished from a resultant, active, or wattless e. m. f.

Induced Current—When, by any means whatever, the total number of lines of force passing through any circuit is changed, an electric current is produced in that circuit. Such a current is called an induced current.

Induced Electromotive Forces—Electromotive forces set up by electrodynamic induction.

Inductance—The capacity for induction possessed by an active circuit on itself, or on neighboring circuits. Self-induction. That property, in virtue of which a finite electromotive force impressed on a circuit does not immediately generate the full current due to the resistance of the circuit, and which, when the electromotive force is withdrawn, requires a finite time for the current strength to fall to its zero value. A property, by virtue of which the passage of an electric current is necessarily accompanied by the absorption of electric energy in producing a magnetic field. A constant quantity in a coil devoid of iron depending only upon its geometrical arrangement, and usually expressed in henrys,

and equal to $\frac{4\pi^2 RN^2}{L}$ where R is the radius of the coil, L the length and N the number of turns.

Induction, Mutual—Induction produced by two neighboring circuits on each other by the mutual interaction of their magnetic fields.

Induction, Self—Induction produced on a circuit at the moment of starting, or stopping, the currents therein by the induction of the current on itself.

Inductive Circuits—Circuits containing certain types of apparatus and known as inductive circuits have the property of storing up a part of the energy supplied to the circuit during a part of each cycle, and restoring this energy to the source during the remainder of the cycle. This causes the reversal of current to take place at an earlier or a later instant than the reversal of voltage, the current being known then as a leading or lagging current. During the time when energy is being delivered to the circuit, the product of voltage and current is positive; that is, the voltage and the current have the same sign. When either voltage or current is reversed with respect to the other so that this product is negative, power is being returned by the circuit to the source, and is then reckoned as a negative. The net value of the energy delivered to the circuit per cycle is equal to the difference between the positive and the negative values of energy in the two periods above referred to. The average value of the power for a given value of voltage and current is then less than the product of the voltage and current (the volt-amperes) and may have any value between the value of the volt-amperes and zero.

Inductive Reactance—Reactance due to self-induction as distinguished from reactance due to a condenser.

Instantaneous Peak—The instantaneous peak of a load diagram is the maximum value of the load shown on that diagram. With reference to a sine wave, the instantaneous peak is the maximum amplitude of the wave.

Insulation Resistance—The resistance existing between a conductor and the earth, or between two conductors in a circuit through insulating materials lying between them. A term applied to the resistance of the insulating material of a covered wire or conductor to an impressed voltage tending to produce a leakage of current. The resistance of any insulation.

Intensity of Field—The strength or density of a magnetic field as measured by the quantity of magnetic flux that passes through it per unit of area of normal cross section.

Intensity of Magnetic Flux—The quantity of magnetic flux per unit of area of normal cross section. The density of magnetic flux.

Interior Conduit—A conduit in the walls or floors of a building, provided for accommodating electric conductors.

Joint Resistance—The combined resistance of a number of parallel connected resistances. (See Resistance.)

Joule—A volt-coulomb or unit of electric energy or work. The amount of electric work required to raise the potential of one International coulomb of electricity one International volt. Ten million ergs.

Joule's Laws of Heating—In any given conductor the heat developed by an electric current in any given time varies directly as the square of the current, and as the resistance, that is, the heat varies as I^2R. Also since the total heat varies as the time, the total heat is

$$I^2RT$$

or, if expressed in calories

$$\frac{I^2RT}{4.2}$$

Kilovolt—One thousand volts.

Kilowatt—One thousand watts.

Kilowatt-hour—The amount of work equal to that performed by an activity of one kilowatt maintained steadily for one hour. An amount of work equal to 3,600,000 joules. One thousand watt-hours.

Lagging Current—A periodic current lagging behind the impressed electromotive force which produces it.

Leading Current—An alternating current wave or component, in advance of the electromotive force producing it.

Lenz's Law—In all cases of induction the direction of the induced current is such as to oppose the motion which produces it.

Lines of Magnetization—A term sometimes applied to lines of magnetic induction, also applied to those portions of the lines of magnetic force which lie within the magnetized substance.

Load—The work thrown on any machine, apparatus or system.

Load, Artificial—A load purposely created, which is intended to replace an equivalent, but not controllable load, as found on the consumer's premises.

Load, Normal—A load as found at the consumer's premises under normal, or usual, conditions for the time under consideration, also that load for which any apparatus is intended to be used.

Load Transformer—Any transformer designed to carry an appreciable electrical load. In laboratory work, or in connection with tests, this term is commonly used to distinguish these transformers from those

small transformers called instrument transformers, used to furnish instruments, or meters, with relatively small currents, or voltages.

Low-Tension—A relative term used to designate a winding or conductor of less voltage than that with which it is related or compared.

Magnet—Any body producing magnetic flux. A body possessing the power of attracting the unlike pole of another magnet, or of repelling the like pole, or of inducing magnetism in magnetizable bodies.

Magnet Coil—A coil of insulated wire surrounding the core of an electromagnet, through which the magnetizing current is passed.

Magnetic Circuit—The path through which magnetic flux passes.

Magnetic Field—The region of magnetic influence surrounding the poles of a magnet. The space or region traversed by magnetic flux in which a magnet needle, free to move, will assume a definite position.

Magnetic Flux—The magnetic lines that issue from and return to the poles of a magnet. The total number of lines of magnetic force in any magnetic field. The magnetic flow that passes through any magnetic circuit.

Magnetic Permeability—Conductivity for magnetic flux. The ratio between the magnetic induction produced in a magnetic substance, and the magnetizing force producing such magnetic induction.

Magnetic Poles—Those parts of a magnetic source from or at which the flux emerges or enters.

Magnetism—That property or condition of matter which accompanies the production of magnetic flux.

Magnetomotive Force—The force which produces magnetic flux.

Maximum Demand—The maximum demand, or load, may be stated in kilowatts, horse power, 16 candle-power lamp equivalents, or any other term specified, but preferably should be stated in terms which leave no opportunity for error, and wherever possible should be stated in kilowatts. Unless otherwise specified, it should always mean absolutely the greatest actual instantaneous maximum demand. If the greatest actual maximum demand is not intended, but it is intended to express the greatest maximum demand for a given day or a given interval of time, then it should be so stated.

Maximum Demand, or Load, Indicators—A maximum demand indicator is an instrument which leaves a record of the maximum load which has existed in the circuit. Such meters are designed not to indicate instantaneous values of load, but rather to record maximum values of load continuing for a definite and predetermined time (Chapter XVII).

Megohm—One million ohms.

Meter, Electricity—An apparatus for measuring commercially the quantity of electricity that passes in a given time through a circuit.

Meter Revolutions—The number of revolutions the disk of a watt-hour meter under test makes during some interval of time under consideration. Abbreviated meter revs.

Meter, Rotating Standard—A watt-hour meter used as a standard and especially designed and constructed for the purpose of testing consumers' watt-hour meters, so as to permit accurate and quick results.

Mho—The unit of conductance. Such a conductance as is equal to the reciprocal of one ohm. A unit of electric conductance of the value of 10^9 absolute units.

Microfarad—One-millionth of a farad.

Microhm—The millionth of an ohm.

Mil—A unit of length used in measuring the diameter of wires equal to the one-thousandth of an inch.

Mil-foot—A resistance standard consisting of a foot of wire, or other conducting material, one mil in diameter. A standard of comparison of resistivity, or conductivity, of wires.

Milliampere—The thousandth of an ampere.

Millihenry—A thousandth part of a henry.

Millivolt—The thousandth of a volt.

Motor—An electric motor is an apparatus for transforming electrical energy into mechanical energy by means of continuously supplying a system of electrical conductors with an electric current which causes a magnetic force to act between the conductors carrying it and the magnetic field, or fields, thereby producing continuous relative motion between the conductors and the magnetic fields.

Motor, the First Elementary—The first electromagnetic rotation was accomplished by immersing a small steel magnet in mercury, one end being weighted with platinum so that it floated in a position nearly vertical; a current was passed downward through a wire which was plunged in the mercury, and about this wire the magnet revolved as long as the current flowed.

By a reversal of this, that is, by using a fixed magnet and a movable conductor, Barlow devised what is known generally as "Barlow's Wheel," the form of which is almost identical with that of Faraday's first dynamo. Instead of turning this wheel, and thus generating a current of electricity, a current is led into it from any convenient source, entering at the axis, and leaving at the circumference, or vice versa. If the wheel or disk be properly placed between the poles of a magnet, rotation will be set up, the direction of which will depend upon the direction of the current

and the position of the magnetic poles. The current which causes motion in this simple machine may come from another precisely like it, except that in it the disk must be turned by hand or by some other source of mechanical energy. The experiment is useful as shown in the interchangeability of the dynamo, which generates a current of electricity,

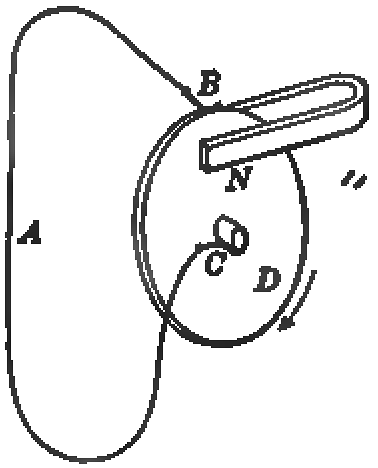


FIG. 38.—Barlow's Wheel.

FIG. 39.—Diagram showing the Reversibility of Barlow's Experiment.

and the motor, which converts that current back into what is generally known as "mechanical energy," the motion of visible masses of matter (Figs. 38 and 39).

Motor-Generator—Motor and generator on the same shaft, for changing alternating current to continuous, and vice versa, or changing current of high voltage and low intensity to current of low voltage and high intensity and vice versa.

Motor, Induction—An induction motor is a rotating machine which transforms electrical power into mechanical power. It consists of two essential parts, namely, the primary or field, to which the line is connected, and the secondary, or armature, in which currents are induced by the action of the primary. Either of these parts may be the the revolving member, but, generally, the field is stationary and the armature revolves, giving rise to the names stator and rotor, respectively.

Multiple Series Circuit—A circuit in which a number of separate sources, or receptive devices, or both, are connected in a number of separate groups in series, and these separate groups subsequently connected in multiple.

Multiple Windings—Independent windings symmetrically disposed upon the same armature, insulated from each other, but brought to different segments of the commutator.

Negative Charge—According to the double-fluid hypothesis, a charge of negative electricity. According to the single-fluid hypothesis, any deficit of an assumed electric fluid. An electric charge of the same character as that produced on silk when rubbed by glass.

Negative Conductor—The conductor connected to the negative terminal of an electric source.

Negative Electromotive Force—Such an e. m. f. as is produced at the free pole of a battery or other source whose positive pole is grounded.

Negative Potential—A potential such as determines a tendency of electricity to flow toward it from the earth or from any point of positive potential. Generally, the lower potential or lower level. That property of a point in space by virtue of which electric work is done by the movement of a small positive charge to that point from an infinite distance.

Negative Terminal—The terminal of a voltaic cell connected with the positive plate or element. The terminal of a source connected with the negative pole. The terminal of a translating device connected with the negative pole of the source.

Normal Current—The current strength at which a system or apparatus is designed to be operated.

Oersted—The name used for the c.g.s. unit of magnetic reluctance. The reluctance offered to the passage of magnetic flux by a cubic centimeter of air when measured between parallel faces.

Ohm—The International ohm, as defined by the International Electrical Congress, which met in Chicago in 1893, "which is based upon the ohm equal to 10 units of resistance of the c.g.s. system of electromagnetic units, is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area and of the length of 106.3 cm."

Ohm's Law—The law of non-varying current strength in a circuit not subject to variation. The strength of a continuous current is directly proportional to the difference of potential or electromotive force in the circuit and inversely proportional to the resistance of the circuit, i. e., is equal to the quotient arising from dividing the electromotive force by the resistance.

Ohm's law is expressed algebraically thus:

$$I = \frac{E}{R}; \text{ or } E = IR; \text{ or } R = \frac{E}{I}$$

If the electromotive force is given in volts, and the resistance in ohms, the formula will give the current strength, directly in amperes.

The current in amperes is equal to the electromotive force in volts divided by the resistance in ohms.

The electromotive force in volts is equal to the product of the current in amperes and the resistance in ohms.

The resistance in ohms is equal to the electromotive force in volts divided by the current in amperes.

The quantity of electricity in coulombs is equal to the current in amperes multiplied by the time in seconds.

Ordinate—In graphics, a vertical distance taken on a line called the axis of ordinates.

Oscillating Current—An oscillatory current. A periodically alternating current of diminishing amplitude.

Oscillograph—An instrument for recording rapid variations of an electric current or pressure, usually consisting of a combination of a suitable form of galvanometer with a photographic recording apparatus.

Parallel Circuit—A term sometimes used for multiple circuit.

Peltier Effect—What may be deemed a converse of the Seebeck effect was discovered by Peltier in 1834, viz., that when an electric current is sent through a junction of two metals (see Peltier bar, Fig. 40), the result is either an absorption or an evolution of heat, according to

FIG. 40.—Peltier Experiment.

the direction of the current. If the current passes in the same direction as that developed by heating the junction, the absorption of heat occurs at the junction, but if in the opposite direction, evolution of heat at the junction results. This is known as the Peltier effect. As this effect is never very intense, it is often masked by the Joule effect resulting from the resistance of the circuit, since the former is proportional to the first power only of the current, while the latter is proportional to the square of the current.

Period—The interval of time between two successive passages of

a vibration through a given point of its path taken in the same direction. The time occupied in performing a complete cycle.

Periodic Function—A periodic function is one which repeats itself after a definite time or period. If any number of simple sine functions

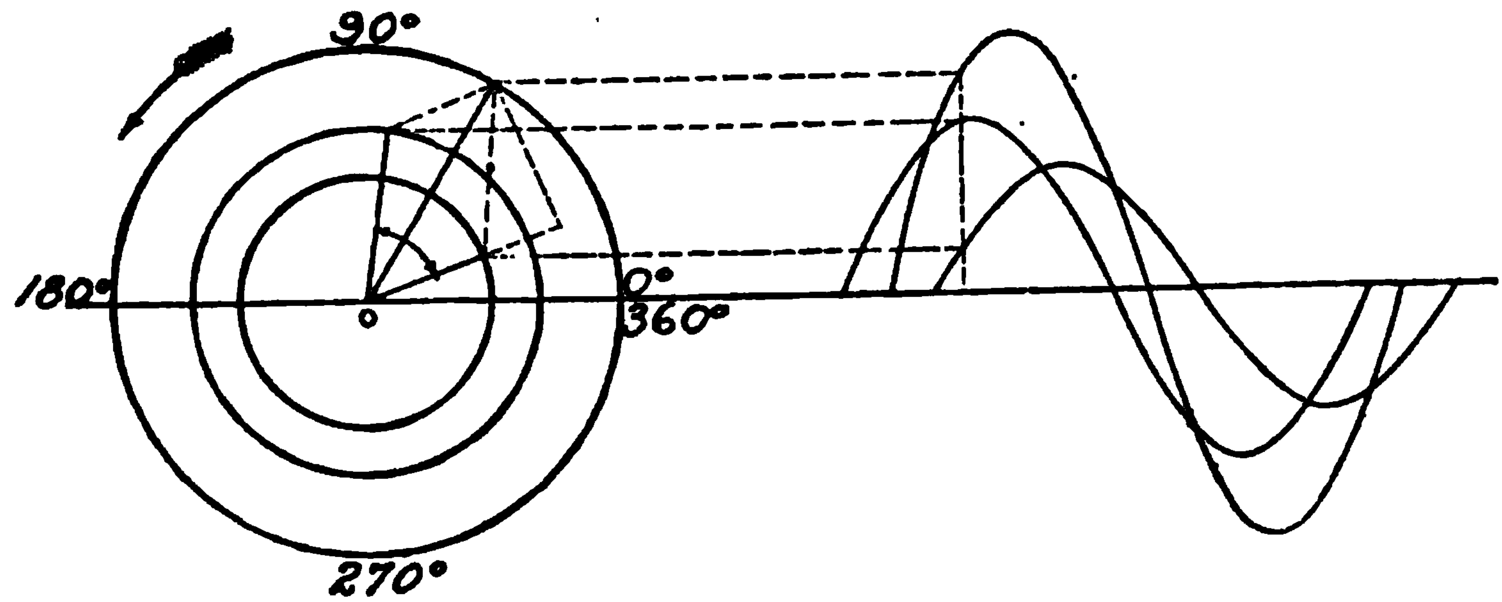


FIG. 41.—Summation of Two Simple Sine Waves to Form a Resultant Sine Wave.

of the same period be added, the resultant sum will be a simple sine function of the same period. This is shown in Fig. 41, for the addition of two simple sine functions or sine waves, and it is evident that, if true for the addition of two, it is true for the addition of any number of simple sine functions. An example of the addition of two simple sine

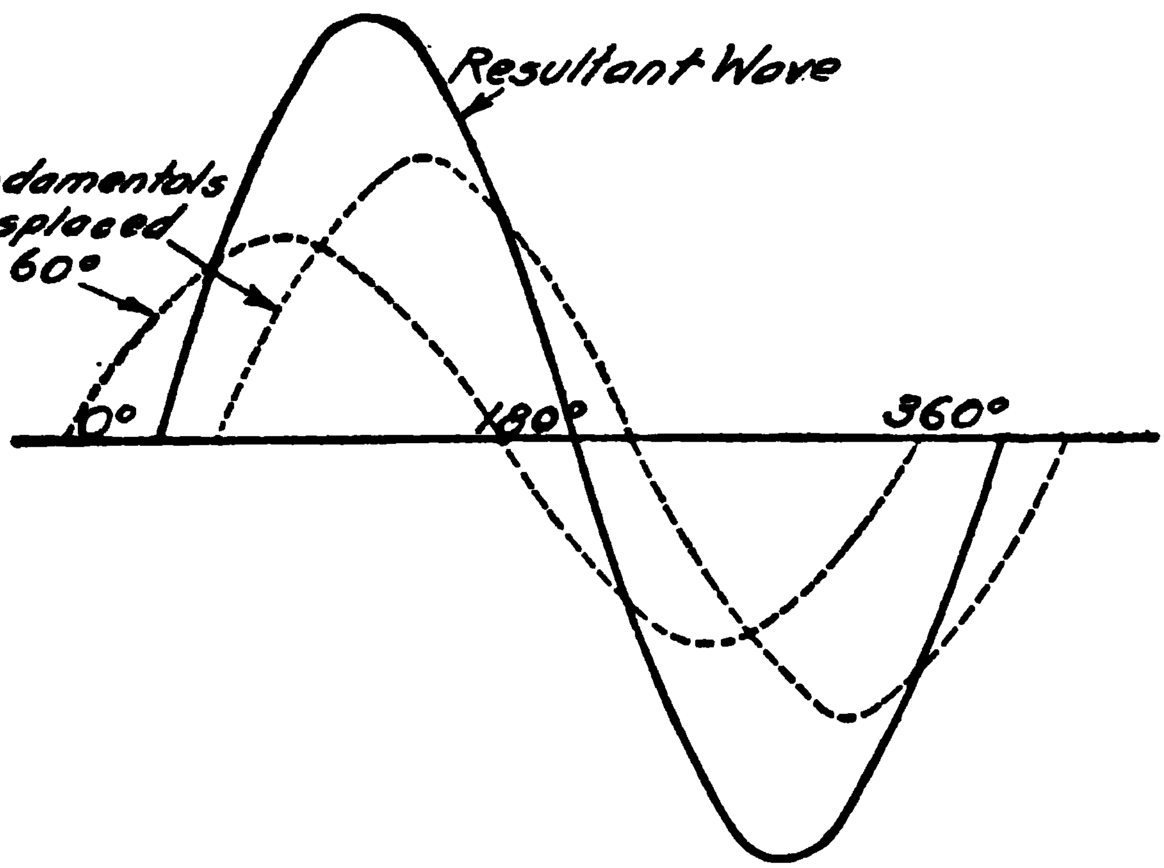


FIG. 42.—Diagram showing the Formation of a Resultant Sine Wave from Two Simple Sine Waves.

functions of the same period is shown in Fig. 42. The resultant curve, represented by the heavy line, is likewise a sine curve.

Permanent Magnet—A name sometimes given to a magnet composed of hardened steel, whose magnetic retentivity is high.

Personal Equation—A constant observational error peculiar to an observer, and depending upon his psychological condition.

Phase Angle—In alternating current systems two or more currents or e. m. fs. which do not come to their maximum values at the same instant are said to be out of phase, or to have a phase difference, and the angle between the vectors which represent these currents or e. m. fs.

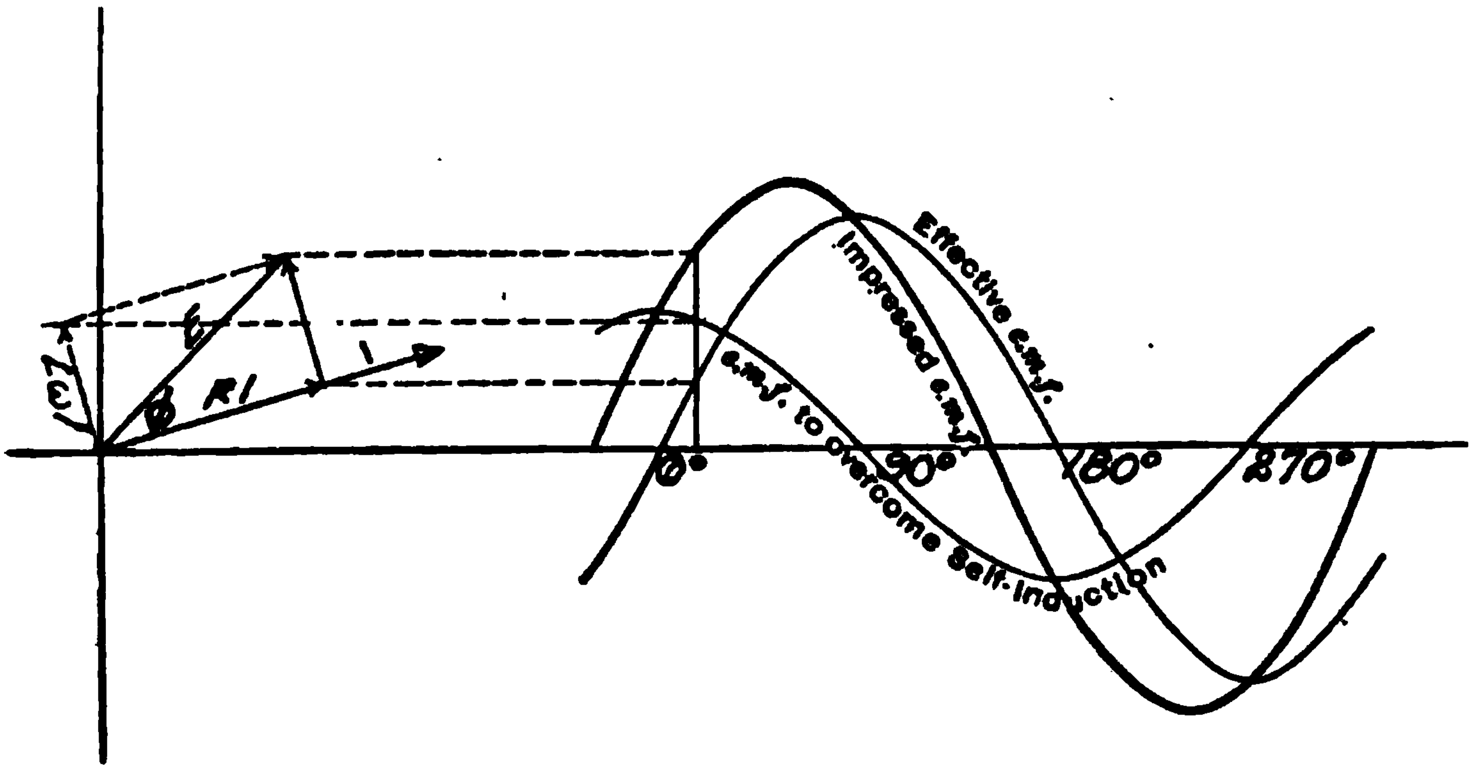


FIG. 43.—Diagram showing the Phase Angles between Three Distinct e.m.fs. and their Vector Representations.

is called a phase angle. If it is measured forward, in the direction of rotation, the angle is called the angle of lead, and if measured against the direction the angle is called the angle of lag (Fig. 43).

Phase Splitting Device—An elementary phase splitting device for starting synchronous motors is shown in Fig. 44. Putting the two sets of coils in parallel with a non-inductive resistance in one branch (see Fig. 44) and a self-inductive resistance (or choking coil) in the other branch. When the motor has started these are cut out; but the motor continues to revolve as a synchronous motor.

Phase Wire—Wires leading from the collector rings (neutral excluded), terminals from transformers or any other alternating current apparatus are commonly called phase wires.

Polarity—The possession of poles, or of opposite properties, at opposite ends. The condition of electric or magnetic differentiation be-

tween properties of electric or magnetic flux depending on, and inherent in, the direction of such flux.

FIG. 44.—Phase Splitting Device.

With reference to the term polarity, pertaining to transformers, the meaning carries with it the designation of the instantaneous direction

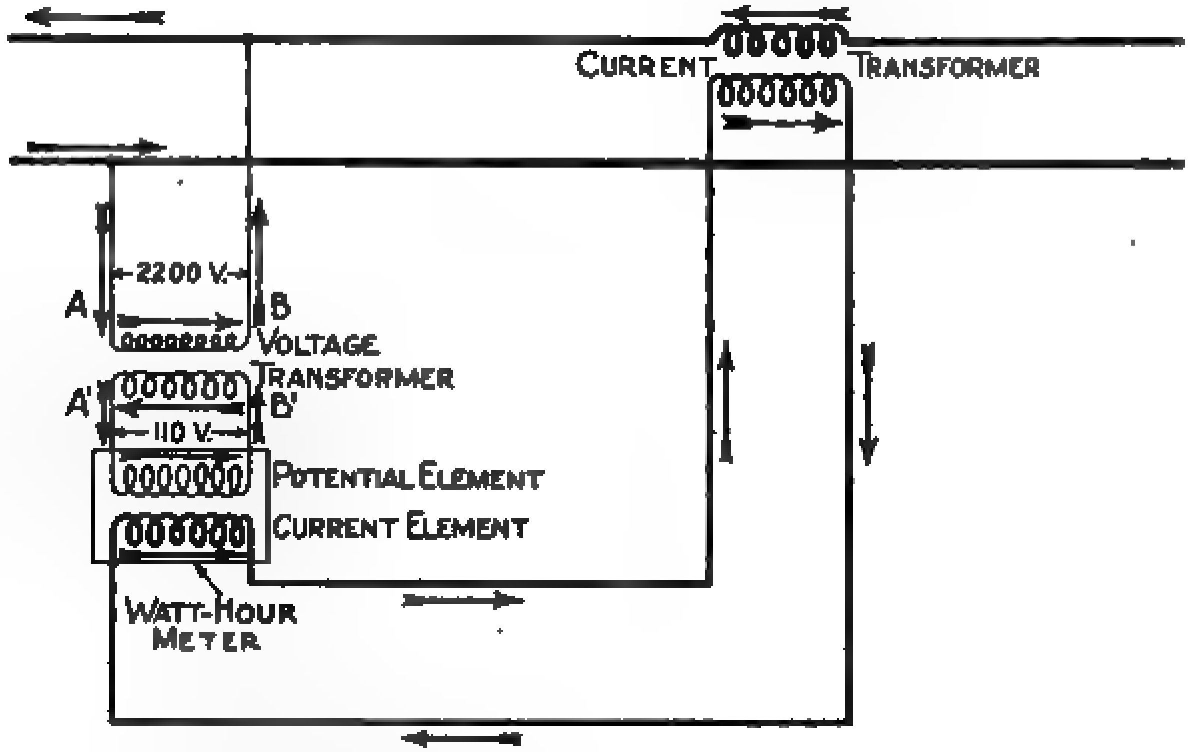


FIG. 45.—Diagram of Instrument Transformer Connections showing that the Directions of Currents in the Watt-hour Meter are the Same as Though the Watt-hour Meter were Connected Directly in the Primary Circuit.

of flow of current. Thus in Fig. 45 the arrows indicate the direction of flow for some interval of time, one cycle, and may be considered as pulsating continuous current for that one half cycle and for the next

one half cycle the same condition may be considered to exist except that the direction of the current has changed. Standard transformers are so designed that currents in the low-tension side of a step down transformer flow as if the high-tension line were connected directly. The following method may be used for testing the polarity of a transformer.

In Fig. 45 high-tension A should be of the same polarity as the low-tension lead A′. With the transformer disconnected from the line, connect the high-tension lead B to the low-tension lead B′. Apply 100 volts, say, to the high-tension side A B of the transformer. The voltage measured from A to A′ should be greater than the applied voltage if the transformer is of the correct polarity. In other words, a transformer connected as shown should act as a booster to the voltage. If the leads A and A′ are not of the same polarity, the voltage measured from A to A′ should be less than that applied as A B.

Positive Charge—According to the double-fluid hypotheses, a charge of positive electricity. According to the single-fluid hypothesis, any excess of an assumed electric fluid. A charge of electricity having a positive potential.

Positive Lead—In a system of parallel distribution, a lead connected with the positive generator terminal, or with the positive bus-bars.

Positive Pole—That pole of an electric source out of which the current is assumed to flow.

Positive Wire—The wire connected with the positive pole of a source.

Potential, Electric—The power of doing electric work. Electric level. Voltage. Electric pressure.

Power—Rate of doing work, expressible in watts, joules-per-second, foot-pounds per hour, etc. Activity. The total amount of work done is independent of time, that is to say, the total work is the same whether it is done in one minute or in one year. But when various amounts of work, done in different times, are to be compared to a common standard of power, the element of time must be considered.

Similarly in the electrical circuit; the total number of joules of work done is independent of the time, but when there are several circuits, the work of each of which is to be compared to a standard, the element of time in which this work is done must be considered.

Power-Factor—The power-factor or an alternating current supply indicates the ratio of actual watts to apparent watts which may be delivered. The apparent watts are equal to the product of the volts and amperes, but owing to possible "phase displacement" the power delivered may be actually less than the apparent power. The power-factor is usually expressed as a decimal fraction. If a pressure of 10 volts delivers

2 amperes at a power-factor of 0.8 (or 80 per cent) the apparent power is 20 watts, while the actual power is 0.8 × 20 or 16 watts.

Practical Units—Definitely related multiples or sub-multiples of the absolute or centimeter-gramme-second units.

Primary—That winding of an induction motor or of a transformer which directly receives power.

Primary Coil of Transformer—That coil of transformer on which the primary electromotive force is impressed. The coil which receives energy prior to transformation.

Primary Currents—Currents flowing in a primary circuit, as distinguished from currents flowing in a secondary circuit.

Proportionate Arms—The two resistances or arms of an electric bridge, whose relative or proportionate resistance only are required to be known, in order to determine in connection with a known resistance, the value of an unknown resistance placed in the remaining arm of the bridge.

Pulsating Current—A current equivalent to the superposition of an alternating current upon a continuous current. A current pulsating in one direction like the blood in the veins.

Quadrant Electrometer—An electrometer in which an electrostatic charge is measured by the attractive and repulsive force exerted by four plates or quadrants on a light needle of aluminum suspended between them.

Quadrature—A term applied to express the fact that one simple harmonic quantity lags 90 degrees behind another.

Quarter-Phase—A term implying the supply of power through two circuits. The vector angle between the e. m. fs. of the circuits is 90 degrees.

Quarter-Phase System—A two-phase system of alternating current distribution employing two currents, out of phase. by a quarter period.

Ratio of Transformation—The ratio between the electromotive force, or current, produced at the secondary terminals of an induction coil or transformer, and the electromotive force, or current, impressed on the primary terminals.

Reactance, Inductive—The inductance of a coil or circuit multiplied by the angular velocity of the sinusoidal current passing through it. or expressed by the formula $x = 2\pi fL = \omega L$, where $\omega = 2\pi f$ and f is the frequency in cycles per second, and L is the coefficient of self-induction.

A quantity whose square added to the square of the resistance gives the square of the impedance, in a simple harmonic current circuit. (See Alternating Current.)

Reactance Coil—A coil for producing difference of phase or for limiting current.

Reactive Circuit—A circuit containing either inductance or capacity alone, or both inductance and capacity.

Reactive Electromotive Force—In an alternating current circuit that component of the electromotive force that is in quadrature with the current and which balances the counter-electromotive force of inductance.

Reflecting Galvanometer—A term sometimes applied to a mirror galvanometer.

Reluctivity—The specific magnetic resistance of a medium.

Residual Magnetism—The magnetism remaining in a core of an electromagnet on the opening of a magnetizing circuit. The small amount of magnetism retained by soft iron when removed from any magnetic flux.

Resistance—The quality of an electrical conductor by virtue of which it opposes an electric current. The unit of resistance is the ohm.

Resistance is that attribute of a conductor or of a circuit which determines the strength of the electric current that can be sent through the conductor or the circuit, around which a constant difference of potential is maintained, as shown by Ohm's law. The resistance of a given conductor is always constant at the same temperature, irrespective of the strength of current flowing through it or the electromotive force of the current, and the resistance of a given conductor increases as the length of the conductor increases; that is, the resistance of a conductor is directly proportional to its length. Also, the resistance of a conductor varies inversely as its sectional area, or the resistance of a conductor of circular cross section is inversely proportional to the square of its diameter.

The combined resistance of several resistances in parallel may be found by taking the reciprocal of the sum of the reciprocals of the individual resistances of the branch circuit. This law follows from the law of conductance, which states that the combined conductance of a parallel branch circuit is equal to the sum of the conductances of the branches, and since the resistance is equal to the reciprocal of the conductance, the reciprocal law holds true, as above stated.

Resonance—In a simple harmonic current, circuit or branch, containing both inductance and capacity, the neutralization or annulment of inductive reactance by capacity reactance, whereby the impedance of the circuit or branch is reduced to the ohmic resistance. In an alternating current circuit, or branch, containing localized inductance and capacity, the reinforcement of condenser pressure, inductance pressure or current strength, due to the mutual neutralization or opposition of inductance and capacity reactances. In an alternating current circuit, or branch, the

attunement of a circuit, containing a condenser to the same natural undamped frequency of oscillation as the frequency of impressed e. m. f. whereby the circuit responds to this frequency more than to any other. In an alternating current circuit, or branch, the annulment of inductive reactance by capacity reactance, whereby the impedance of the circuit or branch is not only reduced to its ohmic resistance, but its current is in phase with its impressed e. m. f.

Resultant Magnetic Field—A single magnetic field produced by two or more co-existing magnetic fields.

Rotating Magnetic Field—A field produced by a rotating current. A magnetic field in which a set of magnet poles is produced, whose successive positions are such as that a rotation of the field is effected.

Secondary—(See secondary winding.)

Secondary Battery—(See storage battery.)

Secondary Winding—That winding of an induction motor or of a transformer which receives power from the primary by induction.

Note: The terms "high-tension winding" and "low-tension winding" are suitable for distinguishing between the windings of a transformer where the relations of the apparatus to the source of power are not involved. (See nomenclature.)

Seebeck Law—In 1822 Seebeck discovered that a current may be produced in a closed circuit by heating a point of contact of two dissimilar metals. Thus, if a piece of bismuth and a piece of antimony be soldered together, and their free ends be connected with a short-coil galvanometer, it is found that if the junction be warmed to a temperature

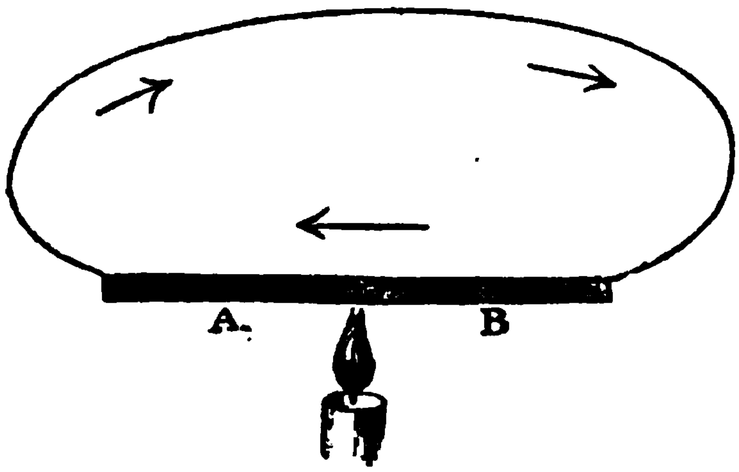


FIG. 46.—Seebeck Experiment.

higher than that of the rest of the circuit, a current flows whose direction across the heated point is from bismuth to antimony, the strength of the current being proportional to the excess of temperature. If the junction is cooled below the temperature of the rest of the circuit a current in the opposite direction is generated. The electromotive force

thus set up will maintain a constant current so long as the excess of temperature of the heated point is kept up, heat being all the while absorbed in order to maintain the energy of the current. Such currents are called thermoelectric currents, and the electromotive force producing them is known as thermoelectromotive force (Fig. 46).

Self-induced Current—A current induced in a circuit on the opening or closing of the circuit, or by changes in the current strength in it.

Self-induction—Induction produced in a circuit by the induction of the current on itself at the moment of starting, changing, or stopping the current therein.

Series Circuit—A circuit in which the separate sources or separate electro-receptive devices, or both, are so placed that the current produced in it or passed through it passes successively through the entire circuit from the first to the last.

Series Multiple Circuit—A compound circuit in which a number of separate sources, or separate electro-receptive devices, or both, are connected in a number of separate groups in multiple, and these separate groups subsequently connected in series.

Short Circuit—A shunt or by-path of negligible or comparatively small resistance, placed around any part of an electric circuit through which so much of the current passes as to virtually cut out the parts of the circuit to which it acts as a shunt. An accidental direct connection between the mains or main terminals of a dynamo or system producing a heavy overload of current. To accidentally produce a short circuit.

Shunt—An additional path established for the passage of an electric current or discharge.

Shunt Circuit—A derived circuit. A branch, or additional circuit, provided in any part of a circuit, through which the current branches or divides, part flowing in the original circuit and part through the new branch or shunt. A circuit for diverting or shunting a portion of the current.

Shunt Ratio—The ratio existing between a shunt and the circuit it shunts. The ratio existing between the total current strength and the current strength in the branch to which the shunt is applied.

Silver Voltameter—A voltameter in which the quantity of electricity passing is determined by the weight of silver deposited.

Simple Alternating Currents—Sinusoidal alternating currents. Simple harmonic currents.

Simple Harmonic Electromotive Forces—Electromotive forces

which vary in such a manner as to produce simple harmonic currents; or, electromotive forces whose variations can be correctly represented by a simple harmonic curve.

Simple Periodic Motion—Simple harmonic motion.

Sine Law—A law of magnitude defined by the sines of angles. A magnitude which follows the sines of successive angles.

Single-phase, Uniphase, Monophase—Pertaining to ordinary alternating currents in a simple alternating current system as distinguished from polyphase currents.

Sinusoidal Alternating Electromotive Forces—Alternating electromotive forces whose variations in strength are correctly represented by a sinusoidal curve. Simple harmonic electromotive forces. (See Figs. 1, 2, and 3.)

Sinusoidal Curve—A curve of sines. A sinusoid. A curve which to rectangular co-ordinates has an ordinate at each point proportionate to the sine of an angle proportionate to the abscissa.

Slide Wire Bridge—A bridge whose proportionate arms are formed of a single thin wire, of uniform diameter and of comparatively high resistance, of some material whose temperature coefficient is low.

Solenoid—A cylindrical coil or wire whose convolutions are circular. An electromagnetic helix. Without any central bar of iron or steel a spiral coil of wire traversed by a current acts as an electromagnet (though not so powerfully as when an iron core is placed in it). Such a coil is sometimes termed a solenoid. A solenoid has

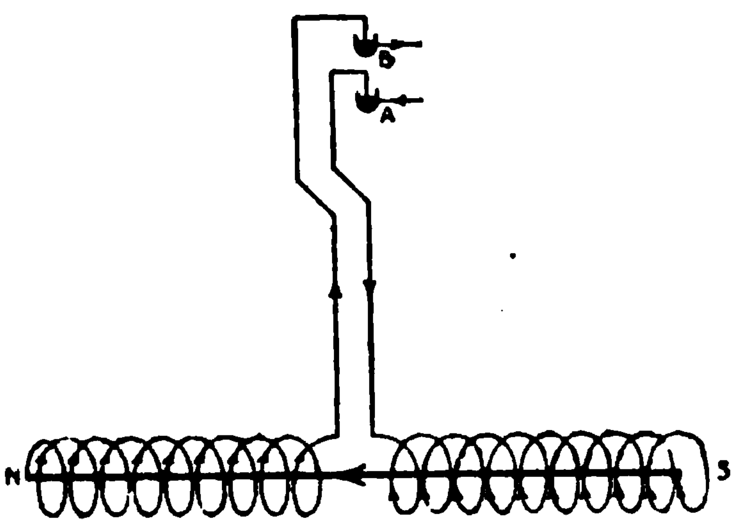


FIG. 47.—A Solenoid.

two poles and a neutral equatorial region. (Ampere found that it will attract magnets and be attracted by magnets.) It will attract another solenoid; it has a magnetic field resembling generally that of a bar magnet. If arranged as shown in Fig. 47, that it can turn round a vertical axis, it will set itself in a north and south direction

along the magnetic meridian. A winding of wire is called a coil. The usual form of coil consists of wire wound on a spool. When the spool is very short and large in diameter the coil is called a circular coil. When a spool is very long in comparison with its diameter the coil is called a solenoid. The solenoid is usually made by winding one or more layers of wire on a long tube.

The magnetic field in a long solenoid is uniform, that is, the field has the same intensity at every point inside of the solenoid and the same direction, namely, parallel to the axis of the solenoid.

Specific Conductivity—The particular conductivity of a substance for electricity. The specific or particular conductivity of a given length and area of cross section of a substance, as compared with the same length and area of cross section of some standard substance. Conductivity with reference to Matthiessen's standard conductivity.

Specific Inductive Capacity—The ability of a dielectric to permit induction to take place through its mass as compared with the ability possessed by a vacuous space of the same dimensions, under precisely the same conditions. The relative power of bodies for transmitting electrostatic stresses and strains, analogous to permeability in metals. The ratio of the capacity of a condenser whose coatings are separated by a dielectric of a given substance, to the capacity of a similar condenser, whose plates are separated by a vacuum.

Specific Resistance—The particular resistance a substance offers to the passage of electricity through it, compared with the resistance of some standard substance. In absolute measurements, the resistance in absoltue units between opposed faces of a centimeter cube of a given substance. In the practical system, the above resistance in ohms. Resistivity, expressed in electromagnetic absolute units as square-centimeters per second.

Split Phase—A difference produced between the phases of two or more alternating currents into which a single-phase alternating current has divided.

Square Mil—A unit of area employed in measuring the areas of cross section of wires, equal to 0.000001 square inch. A unit of area equal to 1.2732 circular mils.

Standard Revolutions—The number of revolutions which the moving element of a watt-hour meter makes when used as a standard for calibrating or testing another watt-hour meter during the measured interval of time.

Star Three-phase System—A system in which all three phase windings are connected together at a common point or neutral point, and the three free ends connected to the circuit.

Starting Torque—The torque required in starting. The torque developed in starting.

Static Voltmeter—A voltmeter operating by electrostatic action, as opposed to a voltmeter operating electromagnetically. A voltmeter in which the moving system is displaced by electrostatic forces. A voltmeter of the electroscope or electrometer type.

Step-down Transformer—A transformer in which a small current of comparatively great difference of potential is converted into a large current of comparatively small difference of potential.

Step-up Transformer—A transformer in which a large current of comparatively small difference of potential is converted into a small current of comparatively great difference of potential.

Storage Battery—A number of separate storage cells connected so as to form a single electric source.

Storage Cell—Two relatively inert plates of metals or metallic compounds immersed in an electrolyte incapable of acting on them until after an electric current has been passed through the liquid from one plate to the other and has thus changed their chemical relations. One of the cells required to form a secondary battery. A term sometimes given to the jar containing a single cell.

Stray Field—Leakage magnetic flux. That portion of a magnetic field which does not pass through an armature or other magneto-receptive device. A magnetic field produced by a source external or foreign to the apparatus under test.

Symmetrical Alternating Current—Any alternating current whose successive semi-periods, waves, or alternations pass through opposite but equal values, or correspond in all respects save direction.

Synchronism—Unison of frequencies in alternating current systems or apparatus. Generally, the co-periodicity and co-phase of two periodically recurring events. The coincidence in cyclic recurrence of two or more periodic variables, without regard to amplitude.

Tangent Galvanometer—An instrument in which the deflecting coil consists of a coil of wire within which is placed a needle, supported at the center of the coil, and very short by comparison with the diameter of the coil.

Thermoelectric Laws—The thermoelectric properties of a circuit are best seen by reference to the simple circuit of Fig. 46 which represents a bismuth-antimony pair united by a copper wire. Volta's law concerning the difference of potentials due to contact states that when all are at one temperature, the difference of potentials between bismuth and copper in one direction is equal to the sum

of the differences between bismuth and antimony, and between antimony and copper in the other direction, and that hence there is equilibrium between the opposing and equal electromotive forces. But when a junction is heated this equilibrium no longer exists and Volta's law ceases to be true. The new electromotive force set up at the heated junction is found to obey the following laws:

(1) The thermoelectromotive force is, for the same pair of metals, proportional (even through considerable ranges of temperature) to the excess of temperature of the junction over the rest of the circuit.

(2) The total thermoelectromotive force in a circuit is the sum of all the separate theromelectromotive forces at the various junctions.

Thermometer, Electric—A device for determining the effects of an electric discharge by the movements of a liquid column due to the expansion of a confined mass of air through which the discharge is passed.

Thomson Effect—The production of an electromotive force in unequally heated homogenous conducting substances. The increase

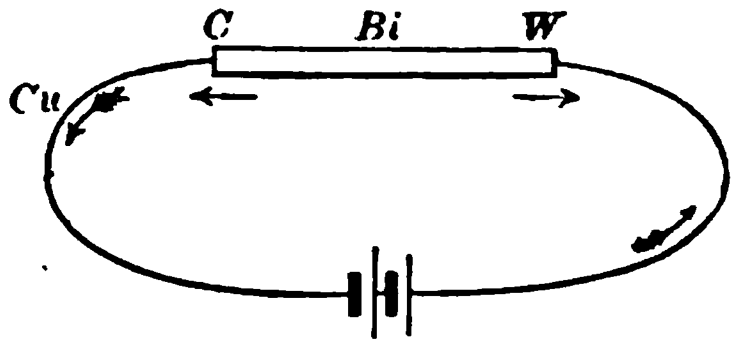


FIG. 48.—Thomson Effect.
C is the Cool End and *W* is the Warm End of the Bismuth Conductor.

or decrease in the difference of temperature in an unequally heated conductor, produced by the passage of an electric current through the conductor (Fig. 48).

Three-phase—Pertaining to an alternating current system on which three, simple, alternating, sine wave e. m. fs., differing in phase by 120 degrees, are impressed (Fig. 49).

Three-phase Transmission—Transmission by means of three-phase currents.

Three-wire System—The three-wire system is usually understood to mean the Edison three-wire system. The outer wires of this system refer to those wires having maximum potential between them and the middle or neutral wire is, for a balanced system, at zero potential; one outer wire, also called the positive wire, having

a potential of approximately 110 volts higher and the other outer wire, also called the negative wire, having a potential of 110 volts lower than the neutral.

Torque—The moment of a force applied to a meter or other machine which causes its rotation. The mechanical rotary or turning force which acts on the armature of a dynamo-electric machine,

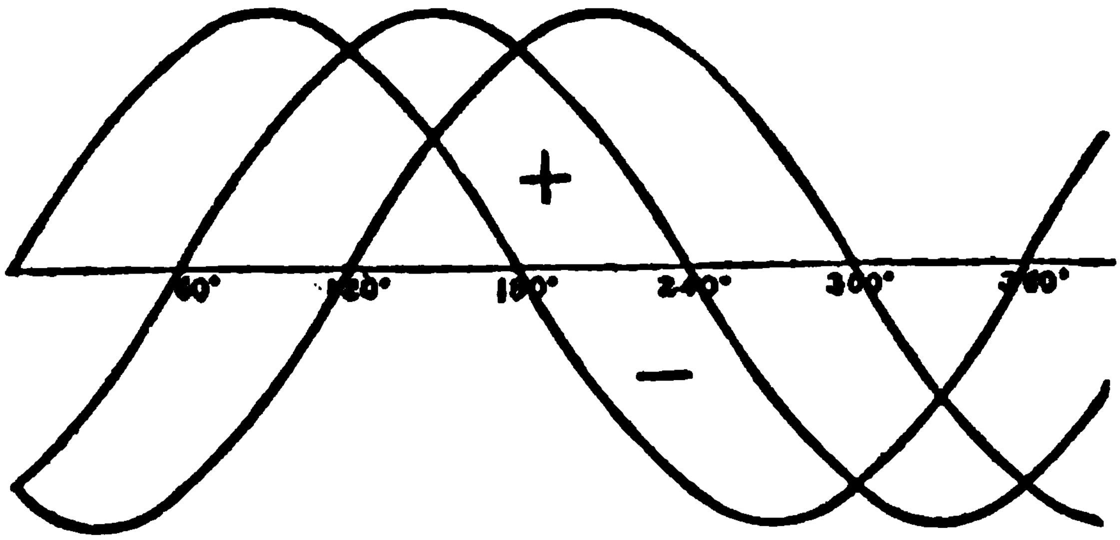


FIG. 49.—Relation of the Waves of Current, or e.m.fs., in a Three-phase System.

or meter, and causes it to rotate. The ratio of the mechanical activity of a motor, at its belt or pulley, to the angular velocity.

Torsion Galvanometer—A galvanometer in which the strength of a deflecting current is measured by the torsion exerted on the suspension system.

Transformer—A stationary piece of apparatus for transforming, by electromagnetic induction, power from one circuit to another, or for changing, through such transformation, the values of the electromotive force or the current.

Two-phase—Pertaining to an alternating current system on which two simple, alternating, sine wave e. m. fs., differing in phase by 90 degrees, are impressed (Fig. 50).

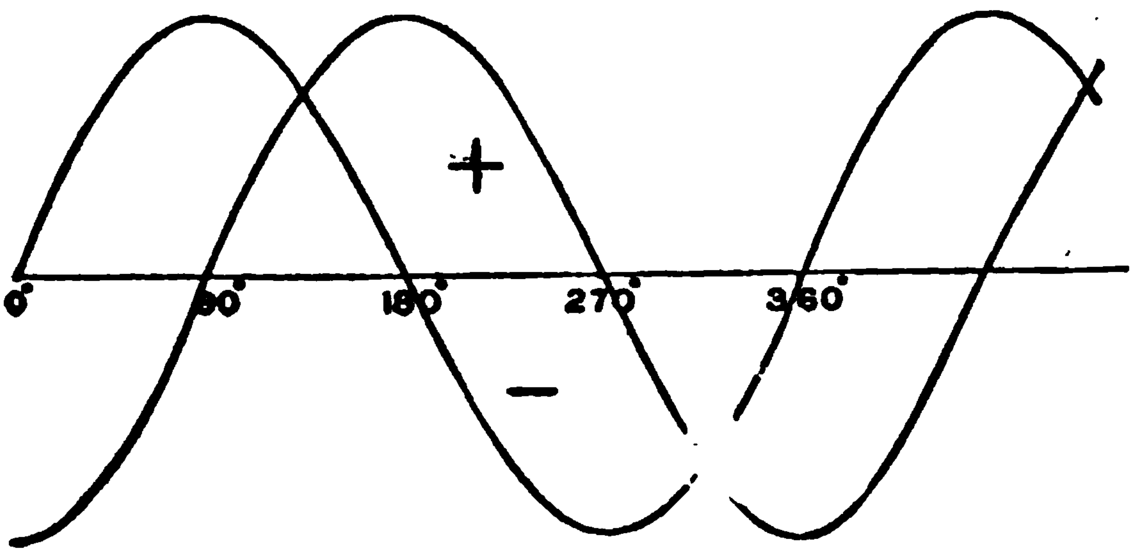


FIG. 50.—Relation of the Waves of Current, or e.m.fs., in a Two-phase System.

Two-wire System—A two-wire system is a sytem for distributing electrical energy by means of two wires.

Unidirectional Currents—Currents that have been caused to take the same direction by means of a commutator.

Vector—A function possessing both direction and quantity.

Vector Diagram—A diagram representing the relations of vector quantities.

Vector Sum—The geometrical sum of two or more vector quantities. Thus, in Fig. 43, by completing the parallelogram formed by the vectors $L\omega I$ and RI, and drawing the diagonal, the vector E is obtained, which is the vector sum of $L\omega I$ and RI. In practice, these vectors are drawn free-hand and the resultants calculated by means

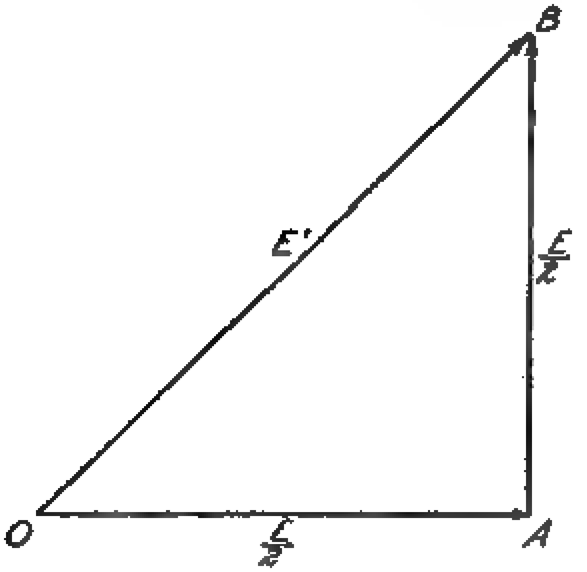


FIG. 51.—Vector Diagram for Calculating the Vector Sum of Two e.m.fs. in Ninety-degree Phase Relation

FIG. 52.—Water Voltameter.

of the geometrical laws. Example: It is intended to find the value of e. m. f. between two wires, across each of which to the neutral is maintained an e. m. f. $\frac{E}{2}$. It is known that these two e. m. fs. differ 90 degrees. In Fig. 51, which is a right angle triangle, OB $=$

$$\sqrt{\overline{OA}^2 + \overline{AB}^2} \text{ or } E^1 = \sqrt{\left(\frac{E}{2}\right)^2 + \left(\frac{E}{2}\right)^2} = \sqrt{2\left(\frac{E}{2}\right)^2}$$

$$\text{i. e., } E^1 = E\sqrt{\frac{1}{2}} = \frac{E}{\sqrt{2}} = \frac{E}{1.41}$$

Volt—The practical unit of electromotive force. Such an electromotive force as is induced in a conductor which cuts lines of magnetic flux at the rate of 100,000,000 per second. Such an electromotive force as would charge a condenser of the capacity of one farad with a quantity of electricity equal to one coulomb.

The International volt, as defined by the International Electrical Congress, which met in Chicago in 1893, "is the electromotive force that, steadily applied to a conductor whose resistance is one International ohm, will produce a current of one International ampere, and which is represented sufficiently well for practical use by $\frac{1,000}{1,434}$ of the electromotive force between the poles of the voltaic cell, known as Clark's cell, at a temperature of 15 degrees C."

Since the Weston cell possessed many advantages over the Clark cell, it was officially adopted in place of the Clark cell as the standard of electromotive force by the London International Electrical Congress of 1908. On January 1, 1911, the U. S. Bureau of Standards adopted a new value for the electromotive force of the Weston normal cell, namely:

$$E = 1.01830 \text{ International volts at 20 deg. C.}$$

This is equivalent to an increase of about 0.08 of one per cent in the value of the International volt.

Voltage—The value of the electromotive force or difference of potential of any part of a circuit, expressed in volts.

Voltaic Cell—The combination of two metals, or of a metal and a metalloid which, when dipped into a liquid or liquids called electrolytes, and connected to a conductor, will produce a current of electricity. A voltaic couple and its accompanying electrolytes.

Voltameter—An electrolytic cell employed for measuring the quantity of electric current passing through it by the amount of chemical decomposition affected in a given time.

Voltameter, Sulphuric Acid, or Water—This instrument consists of a glass vessel containing dilute sulphuric acid. The electrodes are strips of platinum. The current liberates oxygen at the anode and hydrogen at the cathode. The gases are collected in separate vessels, or in a common receiver, in which case the voltameter is given the form indicated in Fig. 52. Usually, the volumes of the liberated gases are measured, but the German chemist Bunsen, in whose hands the most accurate results have been obtained with the water voltameter, recombined the gases by means of the electric spark, and weighed the water thus formed.

Voltmeter—Any instrument employed for measuring differences of potential. (See Chapter V.)

A voltmeter may be constructed on the principle of a galvanometer, in which case it differs from an ammeter or ampere meter, which measures the current, principally in that the resistance of its coils is greater, and that in an ampere meter the coils are placed as a shunt to the circuit.

In the ordinary operation of a voltmeter, the action of the current in passing through a coil of insulated wire is to produce a magnetic field, which causes the deflection of a magnetic needle. Since the resistance of the voltmeter is constant, the current passing, and hence the deflection of the needle will vary with the value of the voltage. The magnetic field produced by the current deflects the magnetic needle against the action of another field, which may be either the earth's field or an artificial field produced by a permanent or electromagnet. Or, it may deflect it against the action of a spring, or against the force of gravity acting on a weight. There thus arise varieties of voltmeters.

Watt—A unit of electrical power. A volt-ampere. The power developed when 44.25 foot-pounds of work are done in a minute, or 0.7375 foot-pounds of work is done in a second; $\frac{1}{746}$ of one horse power.

The International watt is the energy expended per second by an unvarying electrical current of one International ampere under an electric pressure of one International volt.

Watt-hour—A unit of electric work. A term employed to indicate the expenditure of an electric power of one watt for an hour.

Watt-hour Meter—A meter for measuring electrical energy in watt-hours.

Wattless Component of Current—In an alternating current circuit that component of the current which is in quadrature with the impressed e. m. f. and which therefore takes from, or gives, no energy to the circuit.

Wattless Current—That component of an alternating electric current which is in quadrature with the pressure and which, therefore, does no work. The idle current.

Wattless Electromotive Force—The wattless component of e. m. f. in an alternating current circuit. The reactive e. m. f., as distinguished from the active e. m. f. of an alternating current circuit.

Wattmeter—An instrument for measuring the power in any circuit.

Wave Analysis—It is sometimes desired to express analytically an irregular wave, such as Fig. 34, taken by the point-to-point method

or by an oscillograph. The equation of such a curve is obtained on the basis of the mathematical law, that any periodic curve, no matter how irregular, may be represented by an infinite series of sine waves, one of which has the same frequency as the given curve, and the rest have frequencies which are multiples of it. Thus the wave shown in Fig. 34 is a combination of three sine waves, or, as they are called, harmonics; the fundamental wave, the third harmonic, and the fifth harmonic. A rigid analytical proof of this law (Fourier's theorem) would be out of place here. It will be easily seen, however, without any proof, that by suitably selecting the frequency and the phase position of the higher harmonics, the shape of the fundamental sine wave may be distorted in almost any desired way.

When the two halves of the irregular wave, above and below the axis of abscissæ, are identical, no even harmonics can be present, or harmonics having frequencies 2, 4, 6, etc., times higher than the given curve. Such harmonics would increase the ordinates one one-half of the fundamental wave, and reduce by the same amount the ordinates of the other half, making the wave unsymmetrical, which is contrary to the assumption of its being symmetrical. Practically all the waves of voltages and currents, dealt with in electrical engineering, are symmetrical waves, at least those produced by eletromagnetic induction. They consist, therefore, of the fundamental and the odd harmonics only.

Work—When a force acts on a body the product of the force by the distance through which it acts in the direction of the force is called the work performed by the force. Thus when a force applied to a heavy body raises it a certain vertical distance, work is performed by the force, the amount of the work being the product of the force and the distance of ascent; and when a horizontal force draws a body horizontally the work is the product of the force and the horizontal distance. The unit of work is the work done by the unit force in acting through unit distance. When the dyne is taken as unit of force and the cm. as unit of length, the unit of work is that performed by a dyne acting through a cm. and is called an erg. Since this is a very small unit, a multiple of it, namely 10,000,000 ergs, is frequently used and is called a joule.

In practical mechanical work the unit of time is always one minute, and the unit which measures the work performed in a given time is the foot-pound per minute. This unit is called the unit of mechanical power.

Power is, therefore, rate of doing work, and hence the power exerted can always be determined by dividing the work done in

foot-pounds by the time in minutes required to do it. In practical electrical work the unit of time is the second, and the unit which measures the work performed in a given time is the joule per second. This unit is called the unit of electrical power, and has been named the watt.

The equation or formula expressing the power exerted in any electrical circuit is determined as follows: The electrical power is expressed by watts = joules per second; but joules = volt-coulombs, and hence joules per second = volt-coulombs per second. Therefore also, watts = volt-coulombs per second. Now, coulombs per second = amperes. Inserting this value above, watts = volts × amperes, or $P = EI$.

When the power is to be expressed by the current and resistance, the formula is obtained as follows: According to formula $P = EI$. According to Ohm's law, $E = IR$. Substituting this value of $E = IR$ in the formula $P = EI$, we have

$$P = I \times I \times R = I^2R.$$

When the power is to be expressed by the electromotive force and resistance, the formula is obtained as follows: According to formula, $P = EI$. According to Ohm's law, $I = \frac{E}{R}$. Substituting this value of $I = \frac{E}{R}$ in $P = EI$, we have $P = \frac{E}{R} E = \frac{E^2}{R}$.

Zero Method—Any method employed in electrical measurement, in which the value of the electromotive force, the resistance, current or other similar quantities, are determined by balancing against such quantities equal values of the same units, and ascertaining the equality not by the deflection of a needle of a galvanometer or electrometer, but by the absence of such deflections. A null method.

Zero Potential—An arbitrary potential level from which electric levels are measured. The earth's potential.

NOMENCLATURE

Abbreviations used in this Handbook are those which have been adopted by, the A. I. E. E. for the purpose of shortening names when used in connection with definite numerical values.

Name.	Abbreviation.
Alternating current,	spell out.
Amperes,	spell out.
Ampere-hour,	ampere-hr.
Brake horse power,	b. h. p.
Boiler horse power,	boiler h. p.
British thermal units,	B. t. u.
Candle-power,	c-p.
Centigrade,	cent.
Centimeters,	cm.
Circular mils,	cir. mils.
Continuous current,	spell out.
Counter electromotive force,	counter e. m. f.
Cubic,	cu.
Diameter,	spell out.
Electric horse-power,	e. h. p.
Electromotive force,	e. m. f.
Fahrenheit,	fahr.
Feet,	ft.
Foot-pounds,	ft-lb.
Gallons,	gal.
Grains,	gr.
Grams,	g.
Gram-calories,	g-cal.
High-pressure cylinder,	spell out.
Hours,	hr.
Inches,	in.
Indicated horse power,	i. h. p.
Kilogram,	kg.
Kilogram-meters,	kg-m.
Kilogram-calories,	kg-cal.
Kilometers,	km.
Kilowatts,	kw.

Name.	Abbreviation.
Kilowatt-hours,	kw-hr.
Magnetomotive force,	m. m. f.
Mean effective pressure,	spell out.
Miles,	spell out.
Miles per hour, per second,	miles per hr., per sec.
Millimeters,	mm.
Milligrams,	mg.
Minutes,	min.
Meters,	m.
Meter-kilograms,	m-kg.
Microfarad,	spell out.
Ohms,	spell out.
Per,	spell out.
Percentage,	per cent (or % in tabular matter).
Pounds,	lb.
Power-factor,	spell out.
Revolutions per minute,	rev. per min. (or r. p. m. in tabular matter).
Seconds,	sec.
Square,	sq.
Square-root-of-mean-square,	effective, or r. m. s.
Ton-mile,	spell out.
Tons,	spell out.
Volts,	spell out.
Volt-amperes,	spell out.
Kilovolts,	kv.
Kilovolt-amperes,	kv-a.
Watts,	spell out.
Watt-hours,	watt-hr.
Watts per candle-power,	watts per c-p.
Yards,	yd.

Use lower case characters for abbreviations. An exception to this rule may be made in the case of words spelled normally with a capital. Example: "B. t. u." and not "b. t. u.," nor "B. T. U." (British thermal unit). "U. S. gal." (United States gallon); "B. & S. gauge" (Brown & Sharpe gauge).

Use all abbreviations in the singular. Example: "17 lb." and not "17 lbs." (17 pounds). "14 in." not "14 ins." (14 inches).

Use a hyphen to connect abbreviations in cases where the words would take a hyphen if written out in full. When a hyphen is used, omit the

period immediately preceding the hyphen. Example: "3 kw-hr." and not "3 kw.-hr." (3 kilowatt-hours).

Use a period after each abbreviation. In a compound abbreviation, do not use a space after the period. Example: "i.h.p." and not "i. h. p." (indicated horse power).

Never use "P" for "per," but spell out the word. Example: 100 ft-lb. per ton" (100 foot-pounds per ton); "60 miles per hr." (60 miles per hour).

Use "Fig." not "Figure." Example: "Fig. 3" and not "Figure 3."

In all decimal numbers having no units a cipher should be placed before the decimal point. Example: "0.32 lb." not ".32 lb."

Use the word "by" instead of "x" in giving dimensions. Example: "8 by 12 in." not "8 x 12 in."

Never use the characters (′) or (″) to indicate either feet and inches, or minutes and seconds as periods of time.

Use decimals, as far as possible, in place of fractions. Example: "1.25 ft." not "1¼ ft."

In general spell out an adjective qualifying the name of a unit. Example: "Boiler h.p." (boiler horse power). The exceptions to this rule are: "i.h.p." (indicated horse power), "e.h.p." (electric horse power), "b.h.p." (brake horse power), "e.m.f." (electromotive force), "m.m.f." (magnetomotive force).

Use capitals sparingly; when used as units, do not capitalize volt, ampere, watt, farad, henry, ohm, coulomb, etc.

Do not use the expression "rotary" or "rotary converter;" use "converter" or "synchronous converter."

Do not use a descriptive adjective as a synonym for the noun described. Example: a "spare transformer," not a "spare;" a "portable instrument." not a "portable;" "automatic apparatus," not "automatics;" a "short circuit," not a "short."

Do not use the expressions a.c. current or d.c. current; a.c. voltage and d.c. voltage. Their equivalents, "alternating-current current," "direct-current current," "alternating current voltage," "direct current voltage" are absurdities.

Do not use the expressions, "raising transformer," "lowering transformer;" these expressions are ambiguous. Use "step-up transformer," "step-down transformer."

Do not use the words "primary" and "secondary" in connection with transformer windings. Use instead "high-tension" and "low-tension."

UNITS

Symbol.	Quantity.	Equation.	Practical Units.
L	Length		Meter Centimeter Millimeter
M	Mass		Kilogram Gram
T	Time		Minute Second
	GEOMETRICAL UNITS		
S	Surface	L^2	Square meter Square centimeter
V	Volume	L^3	Cubic meter Cubic centimeter
	MECHANICAL UNITS		
a	Acceleration	$\frac{d \text{ velocity}}{d \text{ time}} = \frac{dv}{dT}$	Meters per second per second Kilometers per hour per second
	Force	Ma	Kilogram (weight) Gram " Dyne "
	MAGNETIC UNITS		
$\mathfrak{m}$	Pole strength	$\frac{F}{R}$	Gauss
$\mathfrak{M}$	Magnetic moment	$\mathfrak{m}\, L$	
$\mathfrak{H}$	Field intensity	$\frac{\mathfrak{F}}{\mathfrak{m}}$	Gauss
$\mathfrak{I}$	Intensity of magnetization	$\frac{\mathfrak{M}}{V}$	
ϕ	Flux	$\mu\, \mathfrak{H}\, S$	Maxwell
$\mathfrak{B}$	Flux density	$\frac{\psi}{S}$	Gauss
$\mathfrak{H}$	Magnetizing force	$\frac{4 \pi N I}{10 L}$	Gilbert per cm.
$\mathfrak{F}$	Magnetomotive force	$\frac{4 \pi N I}{10}$	Gilbert

Symbol.	Quantity.	Equation.	Practical Units.
ν	Reluctivity	$\frac{1}{\mu}$	
$\mathfrak{R}$	Reluctance	$\nu\frac{L}{S}=\frac{\mathfrak{F}}{\psi}$	Oersted
μ	Permeability	$\frac{\mathfrak{B}}{\mathfrak{H}}$	
P	Permeance	$\frac{1}{\mathfrak{R}}$	
K	Susceptibility	$\frac{\mathfrak{I}}{\mathfrak{H}}$	
W	Magnetic energy	$\psi\,\mathfrak{F}$	Erg
	Magnetic potential	$\frac{W}{\mathfrak{m}}$	
P	Magnetic power	$\psi\,\mathfrak{F}\,f$	Erg per sec.

Electrical Units

Symbol.	Quantity.	Equation.	Practical Units.
I, i	Current	$\frac{E}{Z}, \frac{Q}{T}, \frac{E}{R}$	Ampere
	Current density	$\frac{I}{S}$	Amperes per sq. inch Amperes per sq. cm.
Q, q	Quantity	$I\,T$	Coulomb Ampere-hour
R, r	Resistance	$\frac{P}{I^2}, \frac{E}{I}$	Ohm
E, e	Voltage, e.m.f., potential difference	$\frac{W}{Q}, I\,R$	Volt
ρ	Resistivity	$\frac{R\,S}{L}$	Ohm per circular mil-foot Ohm per centimeter cube Ohm per sq. millimeter per meter
C, c	Capacity	$\frac{Q}{E}$	Farad Microfarad
G, g	Conductance	$\frac{R}{Z^2}$	Mho
B, b	Susceptance	$\frac{X}{Z^2}$	Mho
Y, y	Admittance	$\sqrt{G^2+B^2}=\frac{1}{Z}$	Mho
γ	Conductivity	$\frac{1}{\rho}$	Mho per centimeter cube
	Time constant	$\frac{L}{R}$	Second Henry per ohm

Symbol.	Quantity.	Equation.	Practical Units.
T, t	Period or cycle	$\frac{1}{f}$	Second
f	Frequency	$\frac{1}{T}$	Cycles per second Periods per second
	Coefficient of Peltier effect	$\frac{W}{I\,T}$	
$\mathfrak{L}$, L	Coefficient of self induction	$\frac{N\,\psi}{I}$	Henry
X_s	Inductive reactance	$2\,\pi\,f\,L$	Ohm
X_c	Condensive reactance	$\frac{1}{2\,\pi\,f\,C}$	Ohm
X, x	Reactance	$X_s - X_c$	Ohm
Z, z	Impedance	$\sqrt{R^2+X^2}$	Ohm
P	Electrical power	$E\,I$, $EI\cos\phi$	Watts Kilowatts
W	Electrical energy	PT	Watt-hour Kilowatt-hour Joule
	Power-factor	$\frac{\text{real } P}{\text{apparent } P}$	
	Inductance factor	$\frac{\text{wattless } P}{\text{apparent } P}$	

E_m, I_m and B_m should preferably be used for maximum cyclic values, E, I and P for instantaneous values, E and I for r. m. s. values and P for the average value or effective power. These distinctions are not necessary in dealing with continuous current circuits. Vector quantities are preferably represented by bold face capitals.

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CHAPTER III

THE PRINCIPLES OF ELECTRICITY METERS

CHAPTER III

The Principles of Electricity Meters

Electricity is known to us only by the effects it produces and its presence is detected, and its quantity determined, according to well-defined laws.

These manifestations may be placed under two general classifications: those embraced in electrostatics and those embraced in electrodynamics. Some bodies may be electrified by friction, for example, a glass rod when rubbed with a silk cloth. Such a rod will attract, or repel, very small bodies, electrifying them by induc-

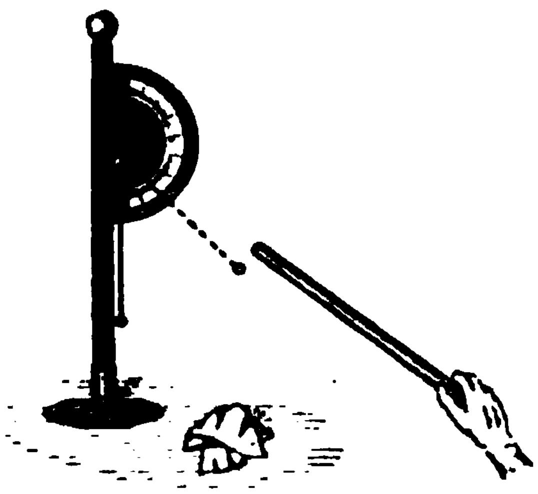


Fig. 53.—Electrostatic Attraction.

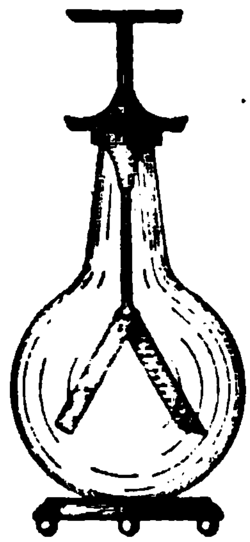


Fig. 54.—Gold Leaf Electroscope.

tion (Fig. 53). The principle of attraction and repulsion between electrified bodies is embraced in the field of **electrostatics** and while it is used in some laboratory and commercial measuring instruments, its field of usefulness is not extensive (Figs. 54, 55, 56 and 57).

The manifestations embraced in **electrodynamics** are due to the "flow" of the electric "current."

This use of the word "flow" and also the word "current" arose from a misconceived analogy between the electric current and a current of liquid in a tube. Both terms will be used in their accepted sense.

In studying the electric current, with a view to its measurement, we will have occasion to investigate the following manifestations:

(a) **Magnetic effect,** resulting from an electric current in a conductor when brought into a magnetic field produced by a magnet, or other electric currents.

(b) **Heating effect,** produced by the passage of an electric current through a conductor.

(c) **Chemical effect,** manifested by the decomposition of a solution by the passage of an electric current through it.

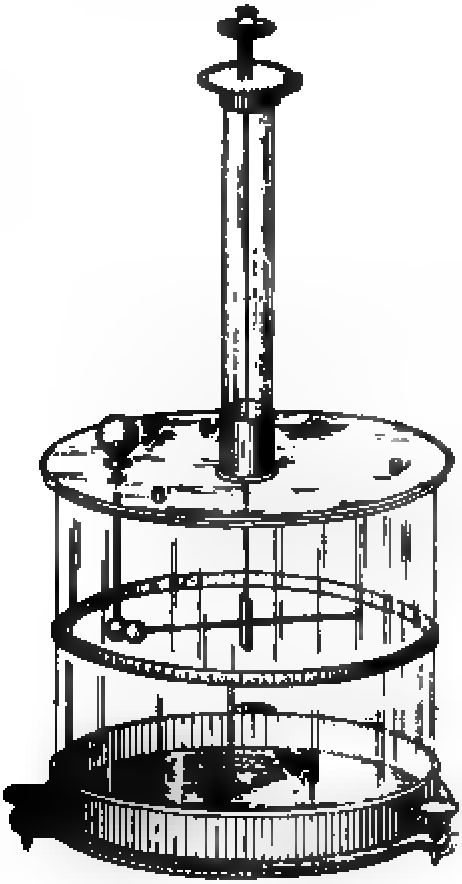


FIG. 55.—Coulomb Balance.

FIG. 56.—Quadrant Electrometer.

Physiological effects are caused by the passage of the current through the human body, but these depend mainly upon the excitation of the nerves, and are probably due either to the heating effect or to the chemical effect of the current.

These three effects are all utilized in the design of various instruments for the measurement of electricity.

Magnetism was originally known as a property of a certain oxide of iron, or the lodestone of the Chinese, by which it was capable of attracting small particles of iron (Fig. 58).

A magnet, as ordinarily accepted, is a piece of steel, or other magnetic substance, having two poles, a north and a south, from which

emanate the **lines of force** known as the **magnetic field** (Fig. 59). The lines of force in the magnetic field from an ordinary bar magnet are shown in Fig. 60.

Early experiments have shown that a similar force to that acting on small particles of iron by a bar magnet exists around a conductor when carrying a current of electricity. It was found that if the discharge of a Leyden jar was passed through a spiral, an enclosed

FIG 58.—Lodestone.

FIG. 57.—Electrostatic Voltmeter for very High Potentials.

FIG. 59.—Steel Bar Magnet.

needle was magnetized, and also that if a wire carrying current were dipped into iron filings, the filings clung to the wire, as shown in Figs. 61 and 62. The **path of the field** of magnetism is concentric with the conductor carrying the current and in any plane at right angles to the conductor is similar to that shown in Fig. 63.

The **direction of the field** is dependent entirely on the direction of the current in the conductor. The direction of the field is also shown in Fig. 63.

It is very important to remember the **relation between** the direction of the **current** in the conductor **and** the direction of the resulting magnetic **lines of force.** Many **mnemonical rules** have been given for this purpose, but it will suffice to quote the particular ones

which are most easily remembered, and which are applicable to the greater number of cases.

The so-called **right-hand rule** for finding the direction of the mag-

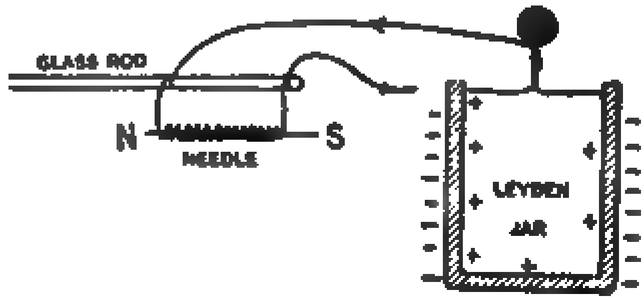


FIG. 60.—Magnetic Field of a Bar Magnet.

FIG. 61.—Leyden Jar and Magnetized Needle Experiment.

netic lines of force around a conductor carrying current is stated thus:

If the right hand is partially closed, and the thumb placed so that it points in the direction of the current flowing in the conductor,

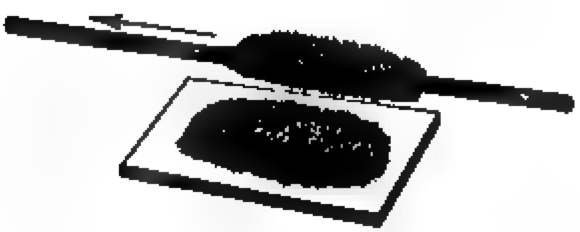


FIG. 62.—Experiment showing Iron Filings Attracted to Wire Carrying Current.

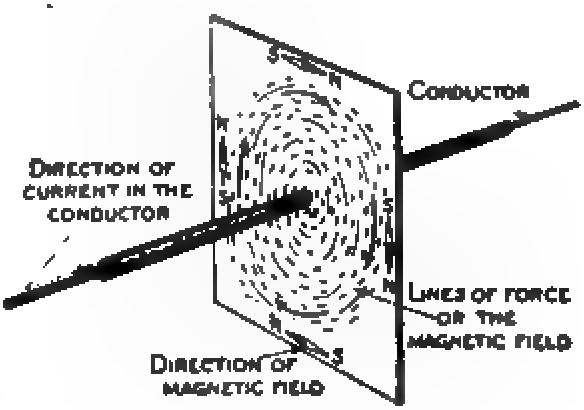


FIG. 63.—Magnetic Field Surrounding a Conductor Carrying Current.

then the direction of the magnetic lines of force is indicated by the other fingers (Fig. 64).

The direction of this field may also be found **by placing a compass needle** over the conductor, in which case the north pole of the

needle will point in the direction of the magnetic field. This is also shown in Figs. 63, 65 and 66.

Another method of finding the direction of the magnetic field is by the so-called **right-hand screw rule.** Assume the current entering at the head of and flowing through a right-hand screw, the observer facing the head of the screw, and the screw turned with a clockwise motion. The direction of the magnetic field will then be clockwise, concentrically around the screw, in the same direction as the rotation of the screw. Conversely, assume the current entering at the

Fig. 64.—Right-Hand Rule.

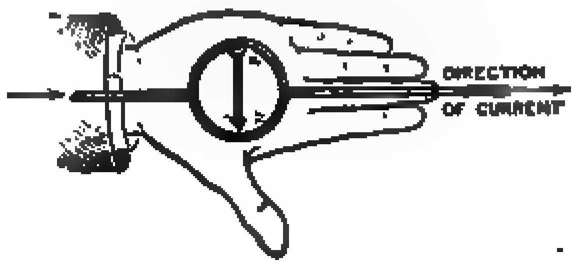


Fig. 65

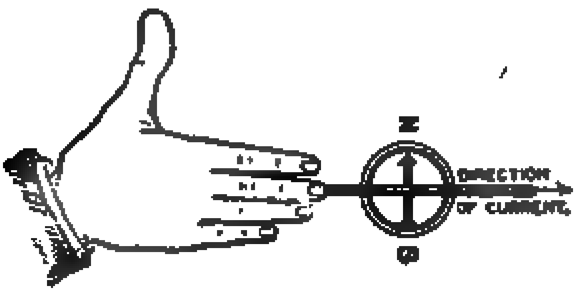


Fig. 66.

Figs. 65–66.—Another Form of Right-Hand Rule

end opposite the head of and flowing through a right-hand screw, the observer facing the head of the screw and the screw turned with a counter-clockwise motion. The direction of the magnetic field will then be counter-clockwise, concentrically around the screw, in the same direction as the rotation of the screw. It is thus seen, that if the current be conceived to be flowing in the direction of the advance of the screw, whether it is being driven, or withdrawn, then the direction of the lines of force, or magnetic field, will be the direction in which the screw is turned, that is, the current flows in the direction the screw moves and the lines of magnetism go in the

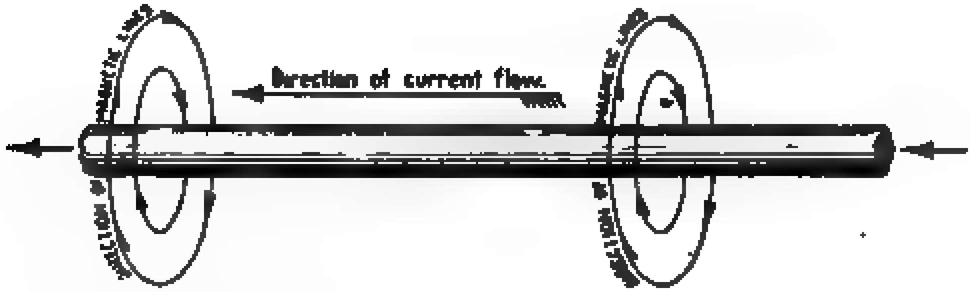


FIG. 67.—Right-Hand Screw Rule.

direction you turn the screw driver. (See Railway Electrical Engineer, Vol. III, No. 10.) (Fig. 67.)

When the current flows in a conductor, a magnetic field exists

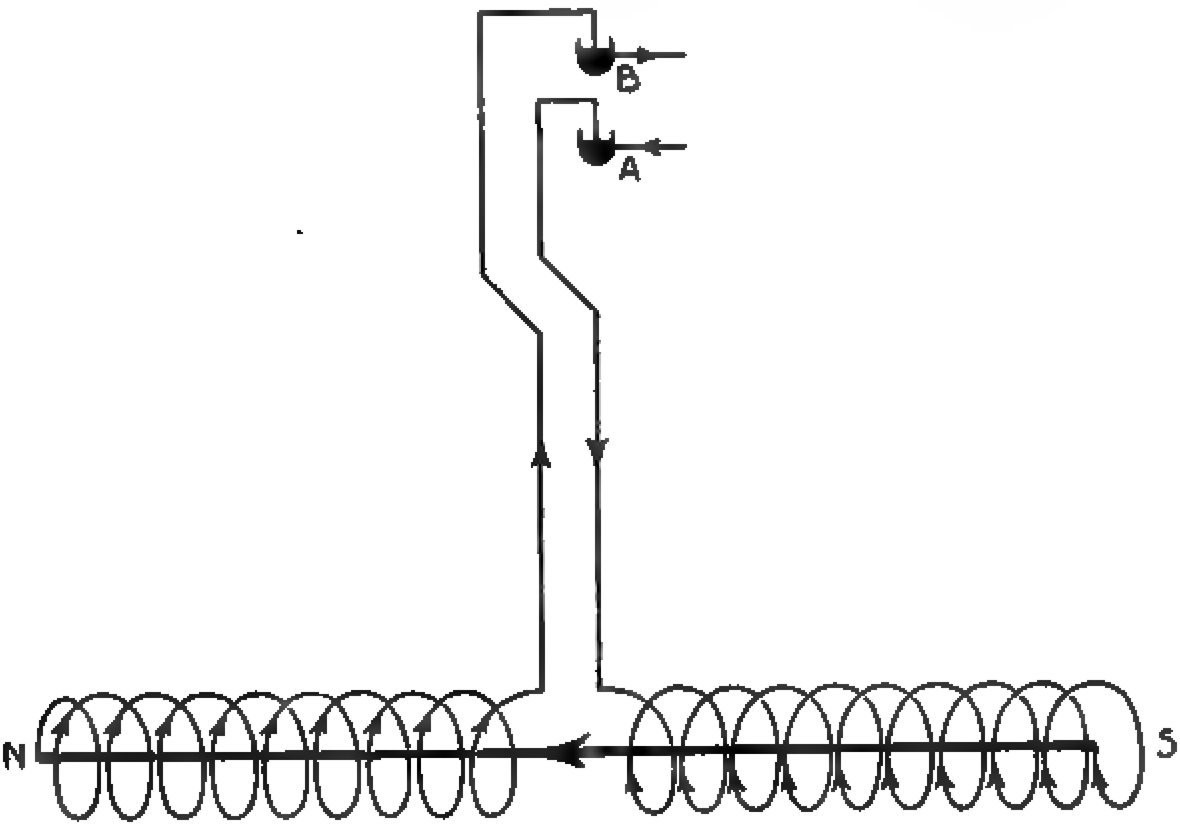


FIG. 68.—Magnetic Effect of Current in a Solenoid.

concentrically around it as explained above. If, however, a magnetic field, from a permanent bar magnet, for example, be moved in the vicinity of a closed conductor, an induced current flows in the conductor and the phenomenon is known as **electromagnetic induction.** Inasmuch as a current flows, a field is set up in turn by the induced current, this field being opposite in direction to the inducing field of the magnet. In other words, there is a magnetic repulsion between the magnet and conductor when one is being approached to the other.

Since the earth is a large magnet, it acts magnetically and therefore mechanically, upon a wire carrying an electric current and freely

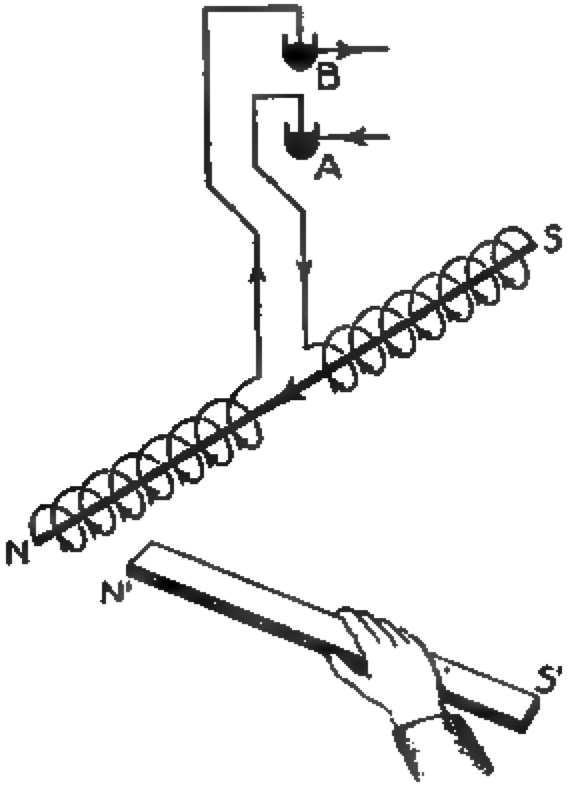


FIG. 69.—Action of a Bar Magnet on a Solenoid.

FIG. 70.—Relation Between Magnetic Polarity and Direction of Current in a Solenoid.

suspended. If the wire is twisted, or wound, into a spiral, or **solenoid,** as in Fig. 68, and suspended by conducting pivots A and B, this effect can be best shown. The arrow heads show the direction of current in the spirals of solenoid, and those placed on the spirals are supposed to be on the front parts of the wires. The wiring passing down the center of the solenoid, while it represents the direction of the current, will equally represent the direction of the magnetic lines of force through the center of the solenoid, the

magnetic polarity of the solenoid being indicated by the letters N and S. A solenoid of this character, when carrying current, will therefore be equivalent to a bar magnet in its action and will behave just like a horizontal compass needle, and has, therefore, all the properties of a magnet. If, then, the north pole of a bar magnet be brought near N (Fig. 69), the latter will be repelled. On the other hand, it will be attracted by the south pole of a bar magnet.

The mnemonical rules given above for remembering the relation between the current in a straight conductor and the concentric mag-

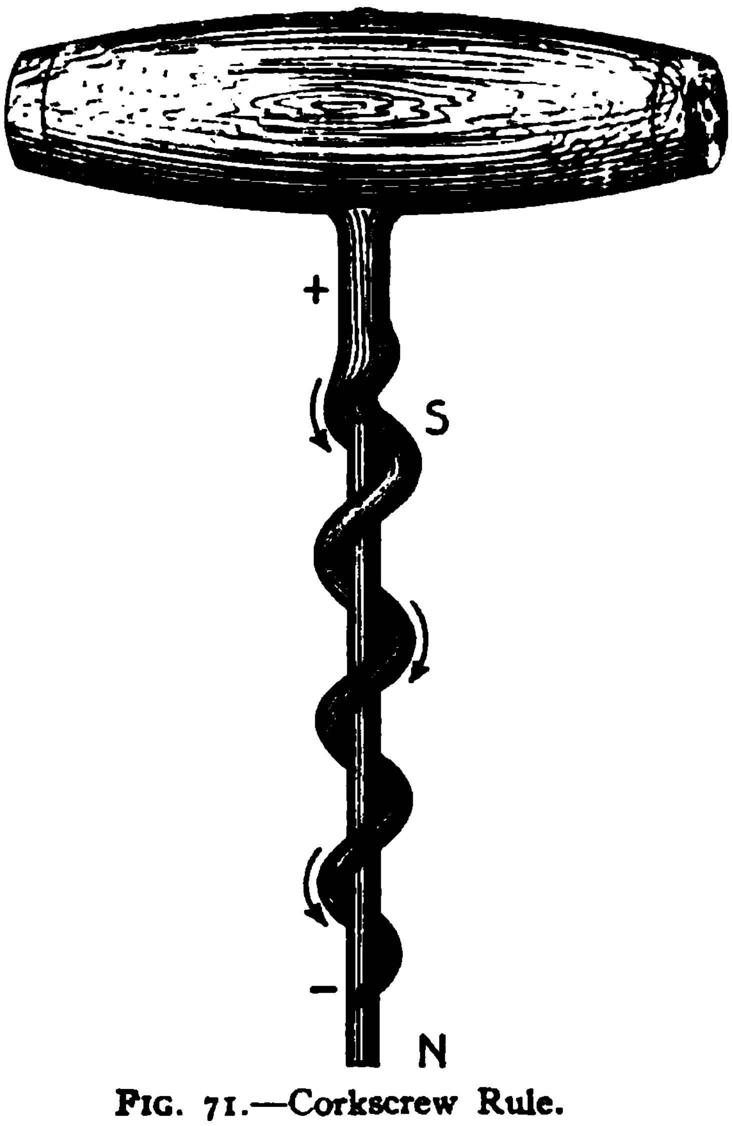


Fig. 71.—Corkscrew Rule.

netic field around it can be easily modified to indicate the **relation between the current in the helical conductor and the magnetic lines** of force passing through the solenoid (Fig. 70), but the following seems to be a more logical and easily remembered rule. It is known as the **corkscrew rule** and is as follows: If the current be supposed to circulate in the spirals of a corkscrew in the direction of rotation of the screw, the direction of the magnetic lines along the axis will be that of the line of advance of the corkscrew. Now the magnetic lines emerge from a magnet at the north pole, and therefore in the above case the forward moving end of the corkscrew (whether front or back) will act as north pole. The rule is illustrated in Fig. 71.

in which the arrows show the direction of the current. If the corkscrew be turned in this direction it will move downward, and the rule tells us that this is the direction of the magnetic lines along the axis; consequently, if a piece of iron be placed along the axis as shown, it will be magnetized so that its lower end is the north seeking pole.

In "General Physics" by Hastings and Beach, the laws of current induction are thus stated:

"Any change in the magnetic field, with respect to a conductor, induces a current in the conductor whose direction is such as to oppose the change which produced it, and the induced electromotive force is proportional to the rate of change of the field.

"The rule for the direction of the induced currents, so far as it relates to those arising from the actual motion of the conductors, or of magnets, was first stated by Lenz, and is commonly known as Lenz's law."

The above conditions are expressed concisely in Lenz's law as follows:

"In all cases of electromagnetic induction the direction of the induced current is such as to tend to stop the motion producing it."

As again stated in the above textbook: "Another statement of the law of induced currents, in the language of Faraday, is, that the induced electromotive force is proportional to the number of lines of force which are cut per second by the conductor. Another statement of the law of induced currents, due to Maxwell, is, that the induced electromotive force in any circuit is equal to the rate of decrease of the magnetic induction through the circuit.

"The direction of the induced current is here called positive with respect to the field, when the relations are those considered in the right-handed screw rule."

In Wiener's "Dynamo Electric Machines," the following mnemonical rule is given:

"The direction of the current flowing, due to the induced electromotive force in any conductor depends upon the direction of the lines of force and upon the direction of the motion, and can be determined by appplying the well-known finger-rule of Professor Fleming. The directions of the magnetic lines, of the motion, and of the current being perpendicular to each other, three fingers of the hand, placed at right angles to one another, are used to determine any one of these directions, when the other two are known. To find the direction of the induced electromotive force the right hand is em-

ployed, being placed in such a position that the t$\mathcal{H}$umb points in the direction of the magnetic lines (of density $\mathcal{H}$) and the Middle finger in the direction of the Motion (Fig. 72), when the Forefinger will indicate the direction of the Flow of the current. Conversely, the direction of the motion which results if a conductor carrying an electric current is placed in the magnetic field of a magnet, is obtained by using in the same manner the respective fingers

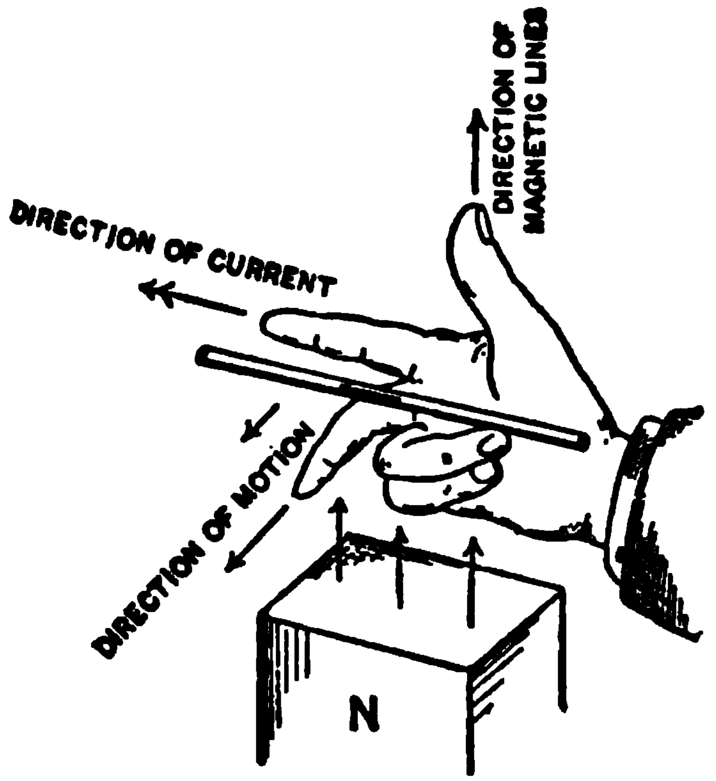


FIG. 72.—Right-Hand Finger-Rule.

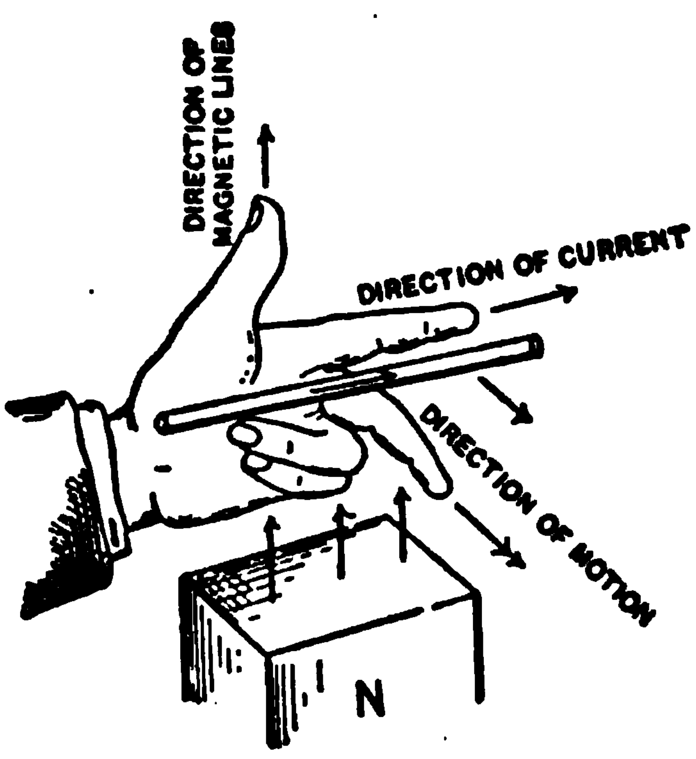


FIG. 73.—Left-Hand Finger-Rule.

of the left hand, as shown in Fig. 73, and then the Middle finger will point to the direction in which the Motion of the conductor will take place."

When a wire is forced through a magnetic field as shown in the moving picture series of Fig. 74, it gathers lines of force about it in the direction as shown, and, remembering our screw driver rule that a screw turned in the direction shown would come out, the current in this wire, Fig. 74, will flow toward the reader. If it were pushed upward, again the magnetic lines would be gathered in the reverse direction and the current would flow away from you.

Lenz's law, and the other laws and principles elucidated above, are made use of in many of the principal measuring instruments of the present time, and are the most important fundamentals in the field of electricity.

The foregoing principles of electromagnetic induction are applicable to alternating currents as well as unidirectional, or continuous, currents. In alternating current fields the direction of the magnetic

field is constantly changing, corresponding to the frequency of the current.

These principles, therefore, are utilized in the design of contin-

FIG. 74.—Development of Lines of Force Around a Wire Moved through a Magnetic Field.

uous, or alternating, current electricity meters and instruments, which are described in the following pages, as may be exemplified by the electrodynamometer and motor types of instruments and meters

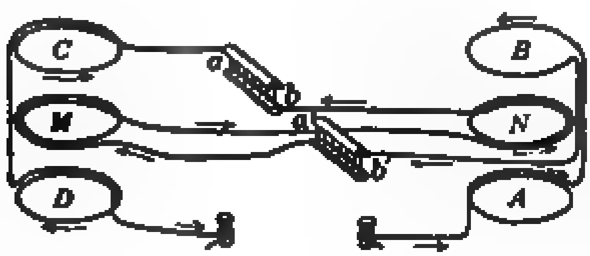


FIG. 75.—Electrical Circuits of a Kelvin Balance Type of Instrument.

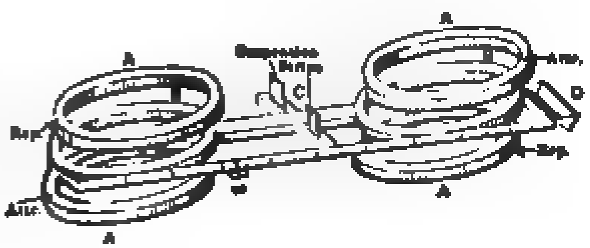


FIG. 76.—Kelvin Balance showing Magnetic Attraction and Repulsion of the Various Coils.

utilizing the magnetic effects (Figs. 75 and 76); the hot wire and expanded fluid types of instruments and maximum load indicators, utilizing the heating effects (Figs. 77 and 78), and the electrolytic instruments and meters utilizing the chemical effects (Fig. 79). The

application of these principles to the different types of **watt-hour** meters and electricity meters utilized in measuring the consumption of electrical energy in a circuit will be reviewed in this chapter.

The function of an **electricity meter** is to integrate—i. e., sum up—and to register in commercial units the electrical energy supplied through it to a circuit.

Ammeters, voltmeters, indicating wattmeters, dynamometers, and similar apparatus, will here be considered as "**instruments**"—not

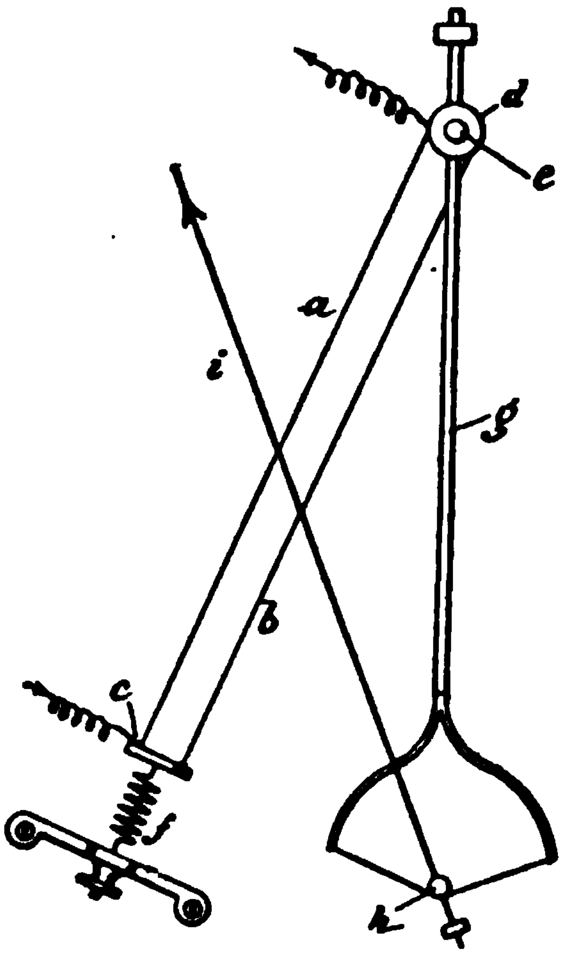


FIG. 77.—Diagram of Whitney Hot Wire Type of Voltmeter.

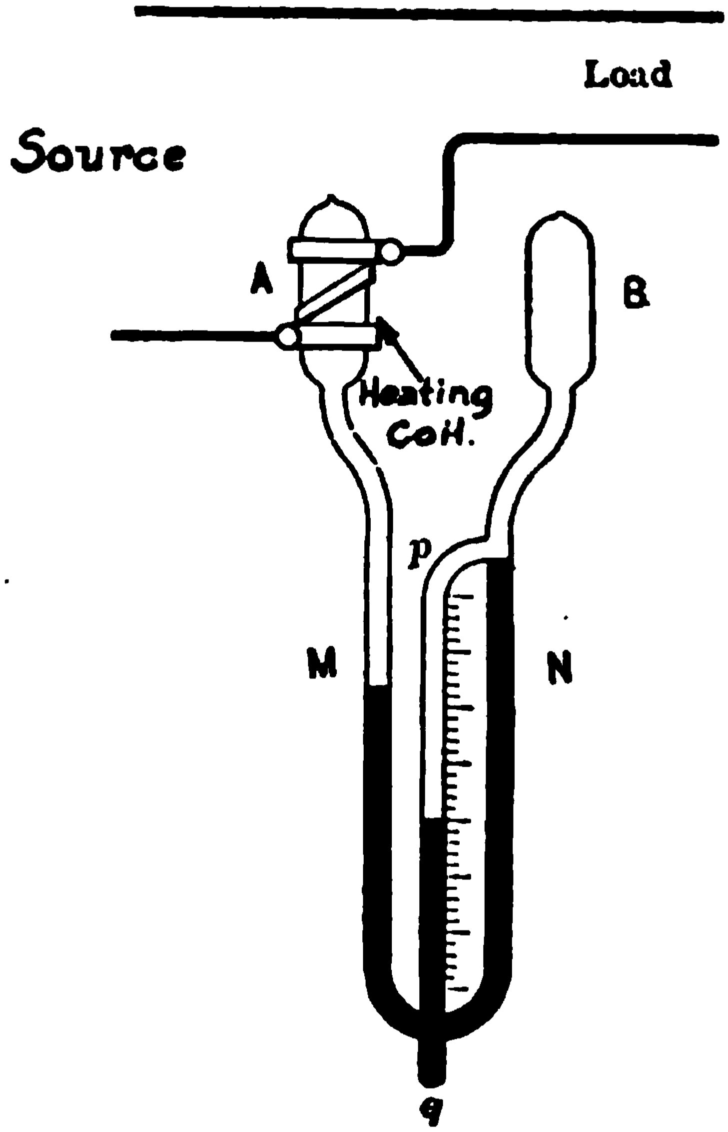


FIG. 78.—Diagram of Wright Demand Indicator.

meters—since they merely indicate the amperes, volts and watts, without respect to the time element which is included in the generally accepted commercial units of electrical energy. (See Chapter V.)

Maximum load indicators, and similar apparatus, indicate the maximum load, and will not be considered in this chapter, since they do not integrate. (See Chapter XVII.)

Curve, or chart-drawing instruments, being **graphic recording instruments**, will not be considered, as they merely record on a disk, or strip, of paper the passing load for each instant and do not integrate

it. The chart from a recording ammeter, or wattmeter, can be integrated by determining the average amperes and watts for each unit of time, and then taking the sum of such averages, or by the use of special planimeters. (See Chapter XVII.)

It is the intention here to consider only integrating meters, and when using the term meter it is to be remembered that it is the integrating meter to which reference is made.

Electricity meters may be divided into two general classes, viz., **ampere-hour meters** and **watt-hour meters.** In the early period of development, electricity meters of the ampere-hour class received the

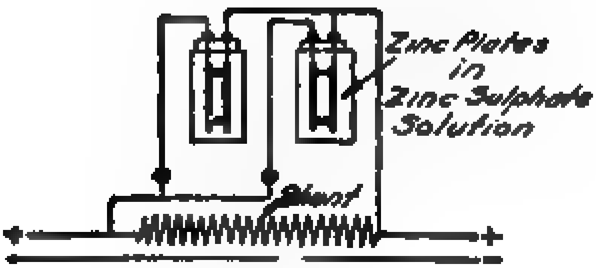


FIG. 79.—Diagram of the Edison Chemical Meter.

FIG. 80.—Early Motor Type of Electricity Meter.

most attention and were most in demand. This was due to their simplicity and consequent low cost, and also to the fact that the watt-hour, or energy, meters were then practically limited to a single design, that of the motor type; whereas there was a number of principles that could be applied in the design of **ampere-hour meters;** as, for instance, **motor** and **electrolytic.**

Meters of the ampere-hour class designed on the induction principle had an advantage, in many respects, over the electrolytic meters and also over motor-type meters of the watt-hour class. The ampere-hour meters were simple in construction, neat and small in design, easily connected to the circuit, and provision was made for

readily adjusting and calibrating them in service. The moving element was light in weight, the meters were free from shunt losses, the first cost was comparatively low and the cost of maintenance was very reasonable. Ampere-hour meters of the chemical type were unsatisfactory, as the consumer could not determine the amount of the consumption, and these meters required too much attention, and the cost of maintenance was too high.

Early in the development of the commercial utilization of electricity, however, the Edison chemical type of electricity meter was designed and used for the measurement of consumption of electrical energy in electric lighting systems. It was, however, an ampere-hour meter and depended upon the principle of the voltameter. A portion of the current was passed, by means of a shunted circuit, from one of two zinc plates to the other, through a solution of sulphate of zinc in which the plates were immersed. Zinc was deposited from the positive plate on to the negative, in direct proportion to the number of ampere-hours of current which had been supplied to the circuit (Fig. 79).

This type of meter has given place to the later motor types of electricity meters. Further reference to this type of meter will be found at the end of this Chapter.

In the use of ampere-hour meters of the early induction motor types a number of vital points must be given due consideration. Older meters of this class and type invariably have a low torque, consequently any change in friction materially affects their accuracy, especially on light loads, and frequently the larger capacity meters of this early class will not register at all until the load has reached several amperes.

Where the drag on the moving element is produced by the fan method, the accuracy of such a meter is affected by barometric changes. Inasmuch as ampere-hour meters are not energy meters, definite voltage. As the voltage on the system may vary somewhat from the fixed standard, it is evident that the ampere-hour class of meters will not always register the true amount of energy.

When ampere-hour meters are used on alternating current circuits, they are suitable only for purely non-inductive loads, and will not give accurate results if connected to circuits supplying motors or other inductive translating devices, as they will record the wattless current, as well as the energy current.

Some of the early types of ampere-hour meters were calibrated in lamp-hours. The manufacturer, or lighting company, determined the average current, that is, amperes consumed by the lamps in use (this amount of current for an interval of one hour being called a

lamp-hour), and the meters were calibrated accordingly. Other ampere-hour meters were calibrated in watt-hours, the normal voltage of the circuit being taken as the voltage at which the current was consumed. The majority of the ampere-hour meters, however, were calibrated to indicate directly in ampere-hour units. Most of these early types of meters have become obsolete, and only a few are now in use (Fig. 80).

The present types of ampere-hour meters are described in Chapter XVI.

It was formerly the general practice of the manufacturers and others to speak of **watt-hour meters** simply as "**wattmeters.**" This practice was, however, apt to be misleading, and it is more correct to call them integrating wattmeters, or watt-hour meters; the last term has now been standardized.

A watt-hour is equivalent to the energy of one watt expended during one hour, and a kilowatt-hour is 1,000 watt-hours. The following is therefore evident (Chapter II):

1000	watts	expended	for	1	hour	$= 1000 \times 1$,	or	1000	watt-hours
2000	"	"	"	0.5	"	$= 2000 \times 0.5$	"	1000	" "
4000	"	"	"	0.25	"	$= 4000 \times 0.25$	"	1000	" "
500	"	"	"	2	"	$= 500 \times 2$	"	1000	" "

Thus a watt-hour meter may be viewed as a meter that automatically multiplies the passing load in watts by the time and records the product, or energy, on a dial face of its register.

At the present time the majority of the manufacturers are supplying to the general market only watt-hour, or energy, meters, but the tendency to again utilize an ampere-hour meter of economical contruction and fair accuracy is strongly forcing itself forward in order to make the profitable service of the large number of very small consumers possible. It would, however, be developed for this specific purpose only, as watt-hour meters are highly satisfactory for all other purposes.

The early types of motor meters of the watt-hour class were somewhat crudely constructed, being large and heavy and having many other objectionable features. There was no provision for adjustments or means for compensating for friction. The moving element was very heavy and the accuracy curve was not all that could have been desired. The early meters of this class have become obsolete, and very few are now in service, having been replaced by the more modern types, for the description of which see Chapter XVI.

Many very marked improvements have been made in the recent watt-hour meters, among which are provisions for adjusting the

meters while in service, the reduction in the weight of the moving element, thereby insuring a longer life of the jewel, and consequently more permanent calibration. The shunt losses have also been reduced to about one-third of the former amount, and the general dimensions and weight have been reduced, consequently the meters are more compact and of more pleasing design.

The **types of meters** now manufactured for the American market may be divided as follows:

Type	Designed for	Class
Electrolytic	Continuous current	Ampere-hour meter
Mercury	Continuous current	Ampere-hour meter
	Continuous current	Watt-hour meter
	Alternating current	Watt-hour meter
Commutated	Continuous current	Watt-hour meter
Induction	Alternating current	Watt-hour meter

The principle of the induction watt-hour meter is quite similar to that of a rotating-field induction motor; and, in general, depends upon the production of a torque or turning moment in a movable closed secondary, or rotating element, by means of a rotating magnetic field; this field being established by the combination of the magnetic fields produced by the series and shunt elements. The interaction between the fields and the opposing fields of the currents induced in the moving element cause the secondary, or rotor, to turn; its speed being directly proportional to the passing energy. To obtain this speed relation, the generally used magnetic brake is employed to provide a retarding torque which is proportional to the speed.

In the early development, experimenters discovered many of the phenomena embodying the elementary principles upon which the modern induction apparatus has been developed. One of the most important discoveries was that the spinning, or revolving, of a metallic disk over which was suspended a magnetic needle would tend to rotate the needle in the direction of the rotation of the disk. This effect, first called the magnetism of rotation, is now generally known as Arago's rotation (Fig. 21). Similar effects were observed by many experimenters, some of whom also discovered that, by reversing the preceding experiments, rotation of a suspended metallic disk could be produced by rotating a permanent magnet placed directly beneath the disk; (Fig. 23); the poles of the permanent magnet being arranged so that when the magnet was rotated the magnetic flux passed through the disk and cut it.

A non-magnetic, metallic disk suspended so as to be free to rotate, under which is placed a permanent steel magnet, arranged to be independently rotated, is the most simple form of induction motor of which the mind can conceive.

When the permanent magnet is rotated the field, or magnetic flux, from the magnet cuts the metallic disk, thus inducing eddy currents therein producing magnetic fields having polarities that oppose the field that originally produced them (Fig 22). It is therefore evident that as the disk is free to rotate it will endeavor to maintain a relative position so that there will be the least cutting of the field of the perma-

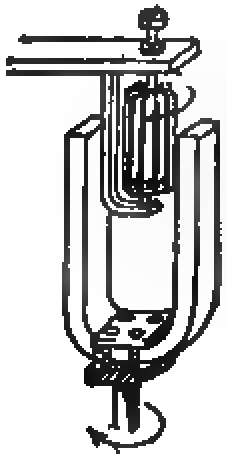


Fig 81.—Bailey's Original Form of Shifting Field Motor.

Fig. 82.—Elementary Form of Induction Motor with Mechanically Rotated Field.

nent magnet; that is, the disk will revolve in the same direction as the magnet.

The direction of the induced current in the disk will be at right angles to the direction of rotation and to the direction of the magnetic flux producing it. The polarity established by the eddy currents flowing in the portion of the disk that is just coming under the magnet pole will be the same as the polarity of the pole inducing it, thus producing a relative repulsion or thrusting effect. The polarity of the eddy currents in the portion of the disk over which the magnet has just passed will

be of opposite polarity to the pole producing it (Fig. 22), consequently an attraction exists that also tends to retard the relative motion. The disk is therefore caused to rotate in the direction of the rotating magnet. The mode of operation of this simple form of rotating field induction motor is quite similar to the method of operation of an alternating current induction meter.

In the first form of induction motor made (Fig. 81), rotation of a non-magnetic metallic disk was produced by means of four fixed electromagnets, energized in such a manner as to cause the magnetism to shift, progressively, between the poles, thus inducing eddy currents in the disk, and by the reaction the disk was caused to rotate in the direction of the progression of the magnetic poles. In this arrangement the electromagnets were energized with continuous current, and the shifting of the poles was accomplished by means of a suitably arranged commutating device. By this method a **shifting magnetic field** was obtained, which is essential to produce rotation of the moving element (Fig. 82).

The theorem that a **true rotating magnetic field** can be produced by combining the magnetic fields of two alternating currents, of exactly the same frequency and amplitude, which differ in phase by 90 degrees—or are in quadrature—will be considered graphically.

Referring to the diagram in Fig. 83, the curves A and B represent two sinusoidal alternating currents differing in phase by a quarter period, or 90 degrees; or, they are in quadrature. The magnetic field produced by the current A, being also sinusoidal, may be represented as traveling along the line X-X', rising toward X and falling toward X'. Likewise the magnetic field produced by the current B may be represented as traveling along the line Y-Y', rising along the line toward Y and falling toward Y' (Fig. 84). The magnetic fields produced have the same period and amplitude, but are constantly changing in strength and have a 90-degree phase relation, or phase angle.

It is evident that when the magnetic field produced by A is at a maximum, B is zero, and produces no field, therefore the resultant field lies along the line OX, having a strength as represented by the line OA. Now, as the field of A decreases, represented by OA^1 and point A^1 on the curve, the strength of the field of B gradually increases, as represented by OB^1, and point B^1 on the curve, along the line OY. By combining these two forces or magnetic fields, the resultant field OR^1 is produced. It is also evident that when the field of A has decreased to A^2 the field of B has increased to B^2, and by combining these two fields the resultant field OR^2 is produced. As the field of A decreases further to the point A^3 the field of B will increase to the point B^3, producing the

resultant field OR^2. Likewise, when the field of A has become zero, the field of B has its maximum value and the resultant field is represented by OB along the line OY.

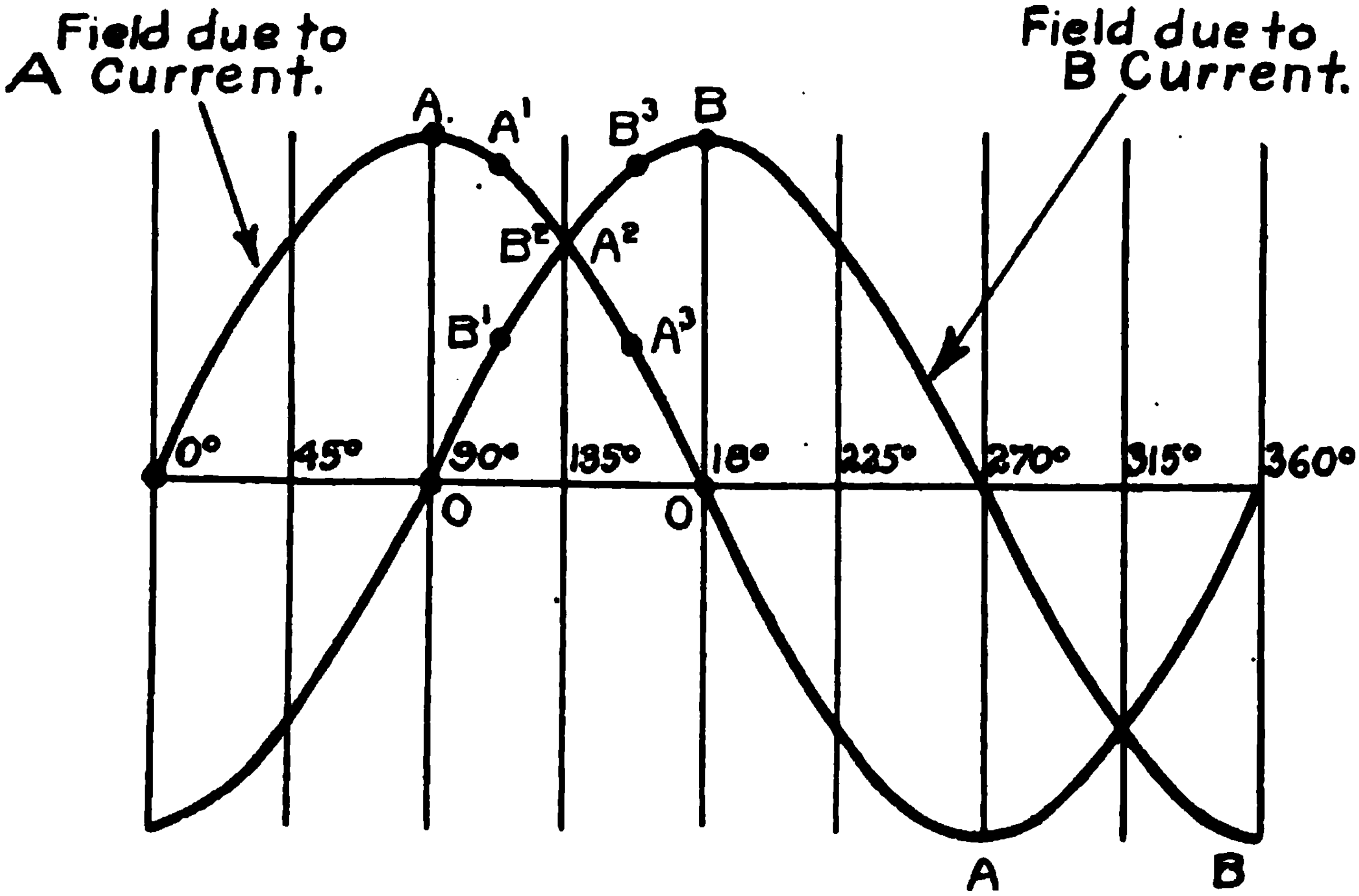


FIG. 83.

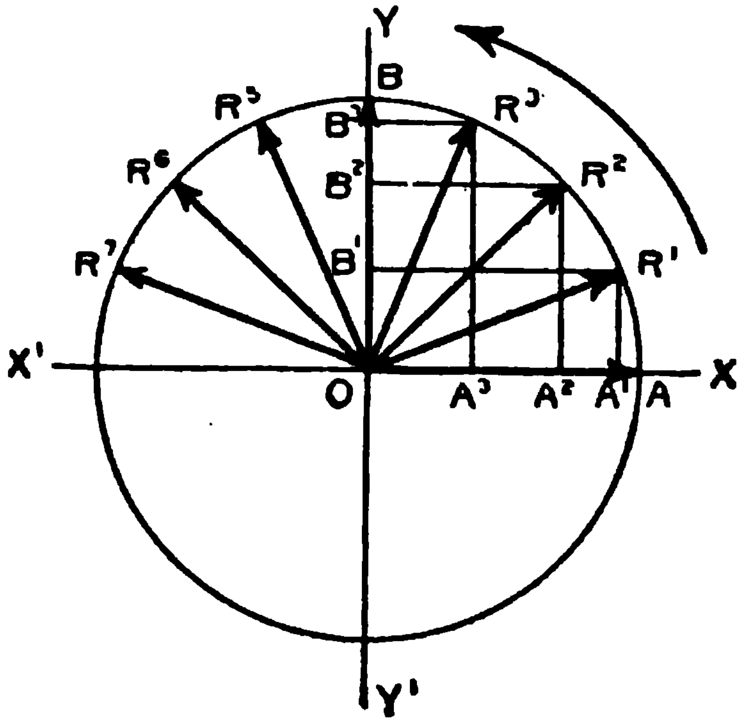


FIG. 84.

FIGS. 83–84.—Two Alternating Currents, in Quadrature, Shown in Wave Form, and the Resultant Rotating Field Produced by Combining the Fields of the Two Currents.

It is clear that the resultant magnetic field has gradually been shifting, or rotating, in a counter-clockwise direction, and if the resultant field be plotted for the remainder of the cycle it will be found to

rotate uniformly around the point O, as indicated by OR^5, OR^6, OR^7, et cetera, and will be of uniform strength, as represented by the radii. Thus the combination of two magnetic fields that vary in the proper manner will produce a constantly rotating magnetic field, the magnitude of which will be the same throughout the cycle.

The production of a rotating magnetic field by a two-phase current, and its application to induction motors is explained below.

As shown, a rotating magnetic field can be produced by two alternating currents, differing in phase relation by 90 degrees. The rotating field thus obtained may be utilized to cause the rotation of non-magnetic, metallic disks and cylinders by means of the eddy currents established in them. The production of rotation in this manner is the real foundation from which induction motors and induction watt-hour meters have been developed, this being the principle that was employed in the first form of alternating current induction motor produced.

Two alternating, sinusoidal currents having a 90-degree, or two-phase, relation may be represented in wave form as shown in Fig. 85 *a*. The curve C represents the magnetic field produced by one current, and the curve D represents the magnetic field produced by the current in quadrature. The ordinates marked 1 to 99, inclusive, divide equally the complete cycle, so that the magnitude of the magnetic fields produced by the two currents may be considered at different instants.

The application of the two currents, as stated, to an induction motor having four poles symmetrically arranged around a closed circuit metallic armature is shown in Fig. 86, *b*, *c*, *d* and *e*. These diagrams also indicate the manner in which the resultant magnetic field is developed and rotates.

Assume that the coils of the motor on the poles marked C and C' which are diametrically opposite, are connected across the circuit, of which C is the current curve, and that the coils on the poles marked D and D', which are also diametrically opposite, are connected to the circuit, giving the curve D.

The direction of the magnetic fields established at the instant represented where ordinate 2 intersects the curves will be N-S from the pole C to D' and from D to C' as shown in *b*.

At the instant represented by ordinate 3 the field produced by the current C will be at its maximum and have a direction N-S from pole C to C', as shown in *c*, while at the same instant current D is crossing the zero line, changing from a negative to a positive value and hence producing no field.

At the instant represented where ordinate 4 intersects the curves,

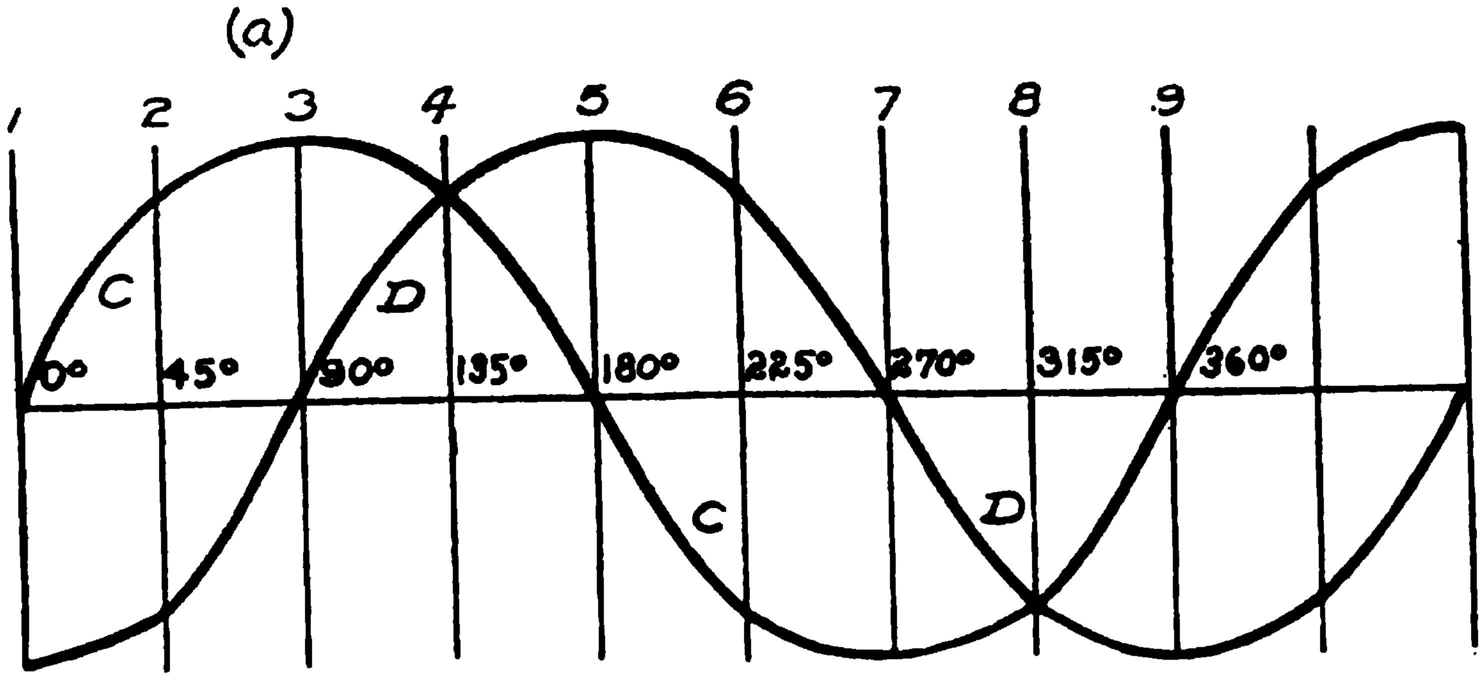


FIG. 85.

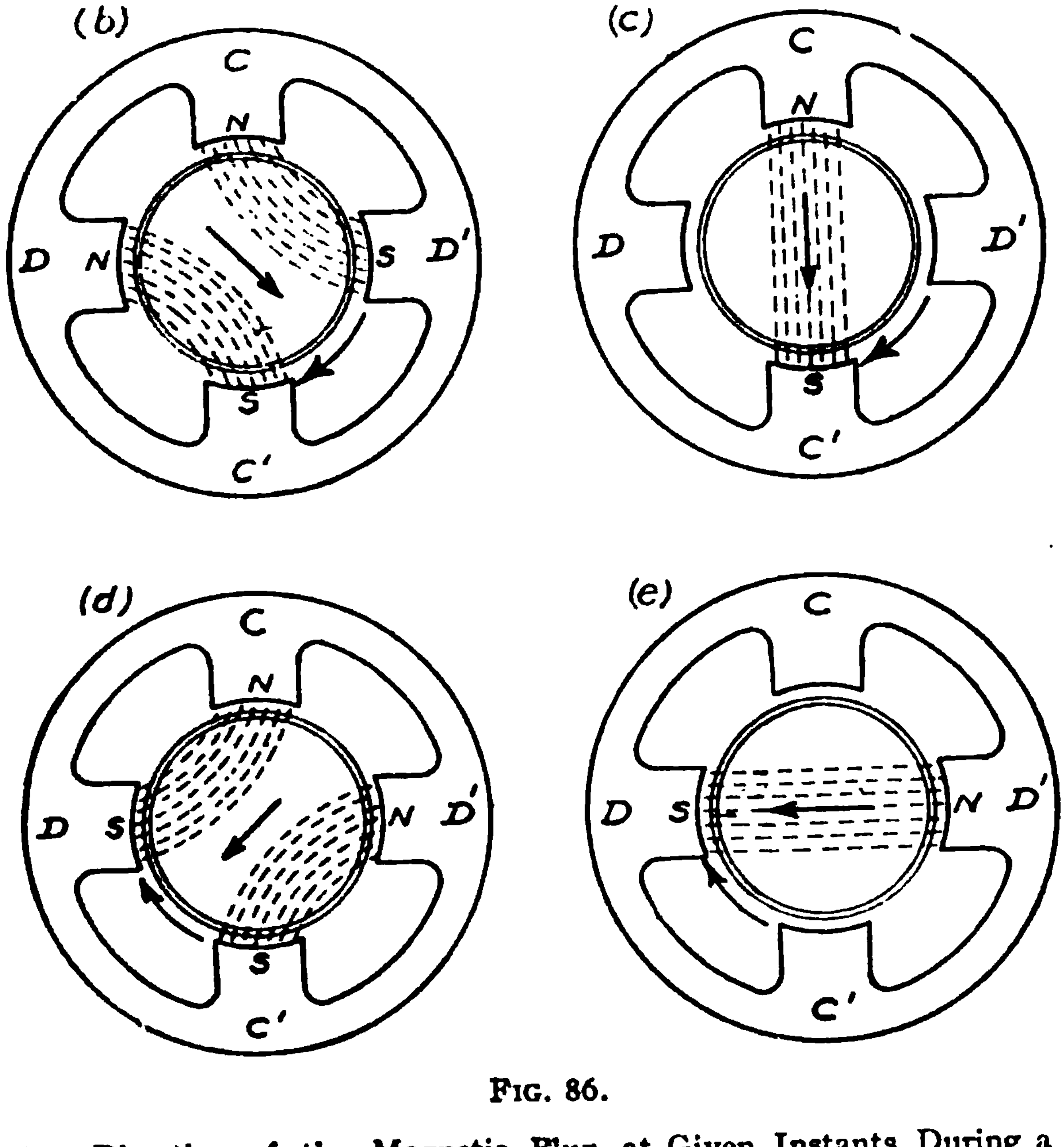


FIG. 86.

FIGS. 85–86. — Direction of the Magnetic Flux, at Given Instants During a Half Cycle, Produced by Applying Two Alternating Currents, having a 90 Degree Displacement, to a Four-pole Motor.

both currents have positive values and the magnetic field produced as shown in *d* is *N-S* from pole *C* to *D* and from pole *D'* to *C'*.

At the instant represented where ordinate 5 intersects the curves, the field produced by current *D* will have a maximum value; at the same instant current *C* will be crossing the zero line, changing from a positive to a negative value and will therefore produce no field. The direction of the field produced by current *D* is *N-S* from *D'* to *D*, as shown in *e*.

If the same method is employed to follow the direction and relation of the fields at the different instants, throughout a complete

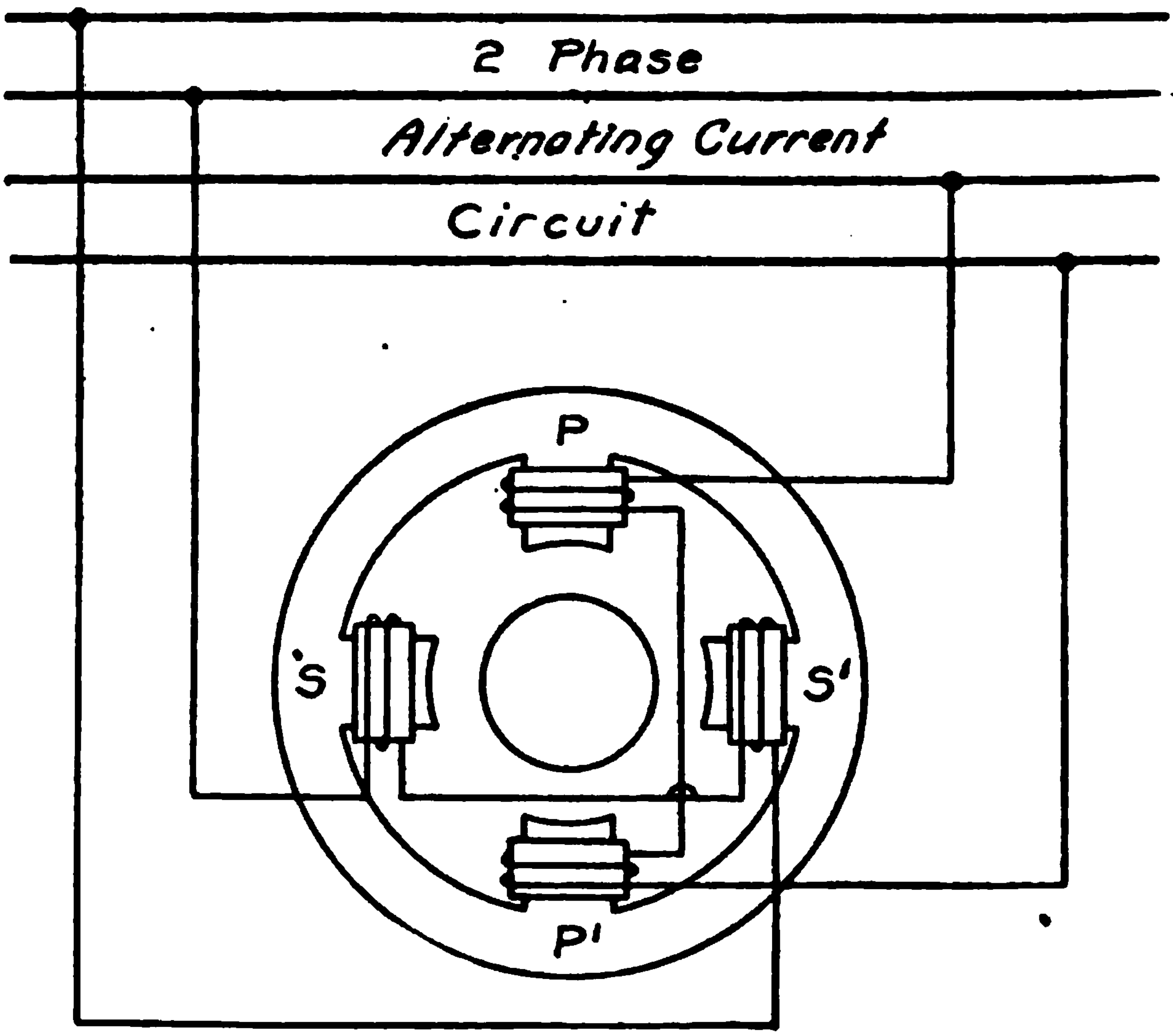


FIG. 87.—Application of Two-phase Alternating Currents to Produce a Rotating Magnetic Field.

cycle, it will be noted that the magnetic poles progress, or shift, and that a traveling field is established which rotates in a clockwise direction.

It has been shown that a **rotating magnetic field** may easily be established by two alternating currents having a 90 degree phase difference, when the field coils are connected independently to different phases, as shown in Fig. 87, but it is important to consider the results that will be obtained if the fields of a similarly constructed motor are connected to a **single-phase** circuit.

Fig. 88 shows the fields of an induction motor with the diametrically opposite poles connected in series, the two pairs *P-P'* and *S-S'* being connected in multiple to a single-phase circuit. As the currents in the two circuits have the same phase relation, the magnetic fields produced are also in phase and will rise and fall simultaneously in both circuits, reversing in direction with each reversal of the alternating current wave. The magnetic fields produced will alternate between the poles *P* and *S'* and *S* and *P'*, as shown by the

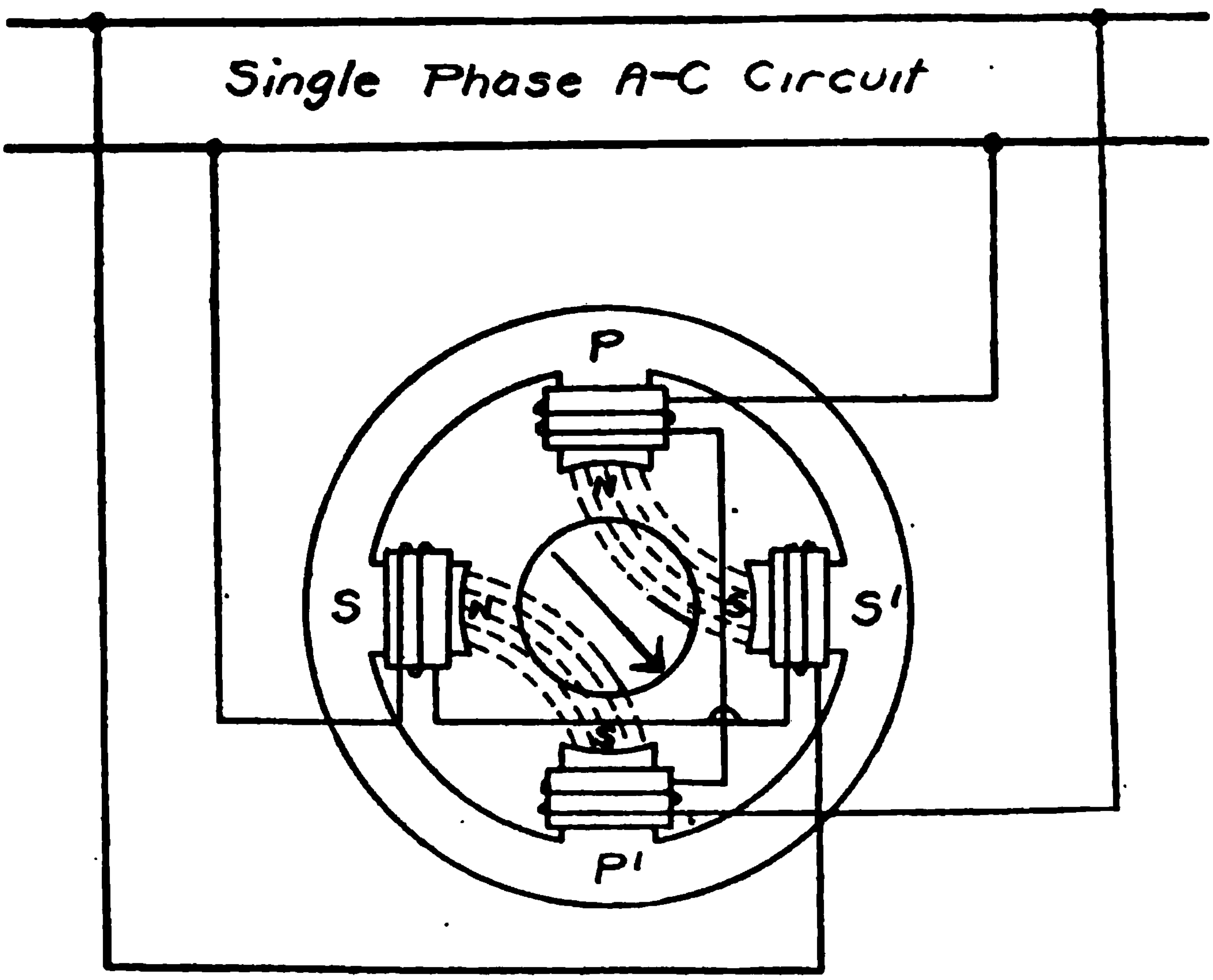


FIG. 88.—Field of a Single-phase Current, Alternating Between the Poles of an Induction

dotted lines in the diagram, therefore no rotating field traveling from one set of poles to the other will be established.

It has been clearly demonstrated that a rotating magnetic field can be established by a combination of fields produced by alternating current circuits having two phases, and this is the principle that is so generally applied in alternating current polyphase induction motors. However, in the design of alternating current induction watt-hour meters it is not necessary to use a polyphase circuit, as a simple method may be employed to produce a rotating field by means of a single-phase current.

In this method two independent branch circuits are necessary,

both being connected in parallel to the mains of a single-phase circuit, as shown in Fig. 89. A non-inductive resistance, *R*, is connected in series with branch circuit *A*, causing practically no phase displacement. A coil, *L*, having a very high inductance and a small resistance, is connected in series with branch circuit *B*. This produces a phase displacement between the currents in the branch circuits that approaches 90 degrees sufficiently to produce a rotating

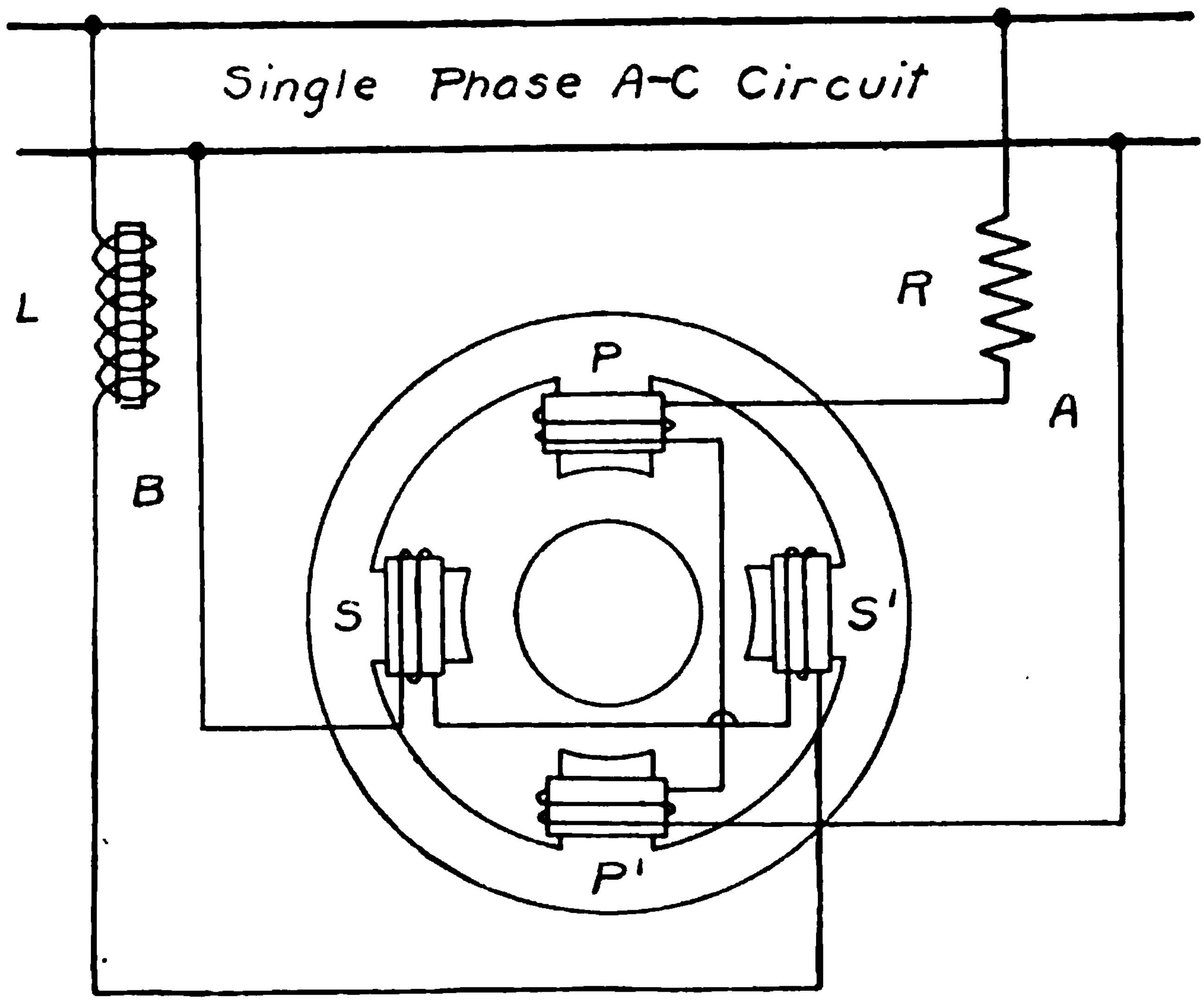


Fig. 89.— Method of Applying a Single-phase Current to a Four-pole Induction Motor so as to Produce a Rotating Field.

magnetic field. It is this principle of which advantage is taken in the design of all alternating current induction watt-hour meters.

This split-phase method of producing a rotating field is sometimes referred to when describing the principles of operation of induction watt-hour meters. This method, however, was originally suggested as a means of starting two-phase induction motors on a single-phase alternating current circuit by employing such an arrangement for "splitting" the phase (Fig. 44). Two branch circuits are used to connect the field coils to the mains. An inductance is connected in series in one branch and a resistance is connected in the other branch; the arrangement being quite similar to that previously described.

A phase splitting device is required which consists of an apparatus to switch the inductance and resistance in and out of circuit. With this arrangement a rotating field is established that produces sufficient torque to start the motor, after which the fields are connected direct to the main circuit.

The method in which the foregoing principles are directly applied in the design of an induction watt-hour meter is represented in

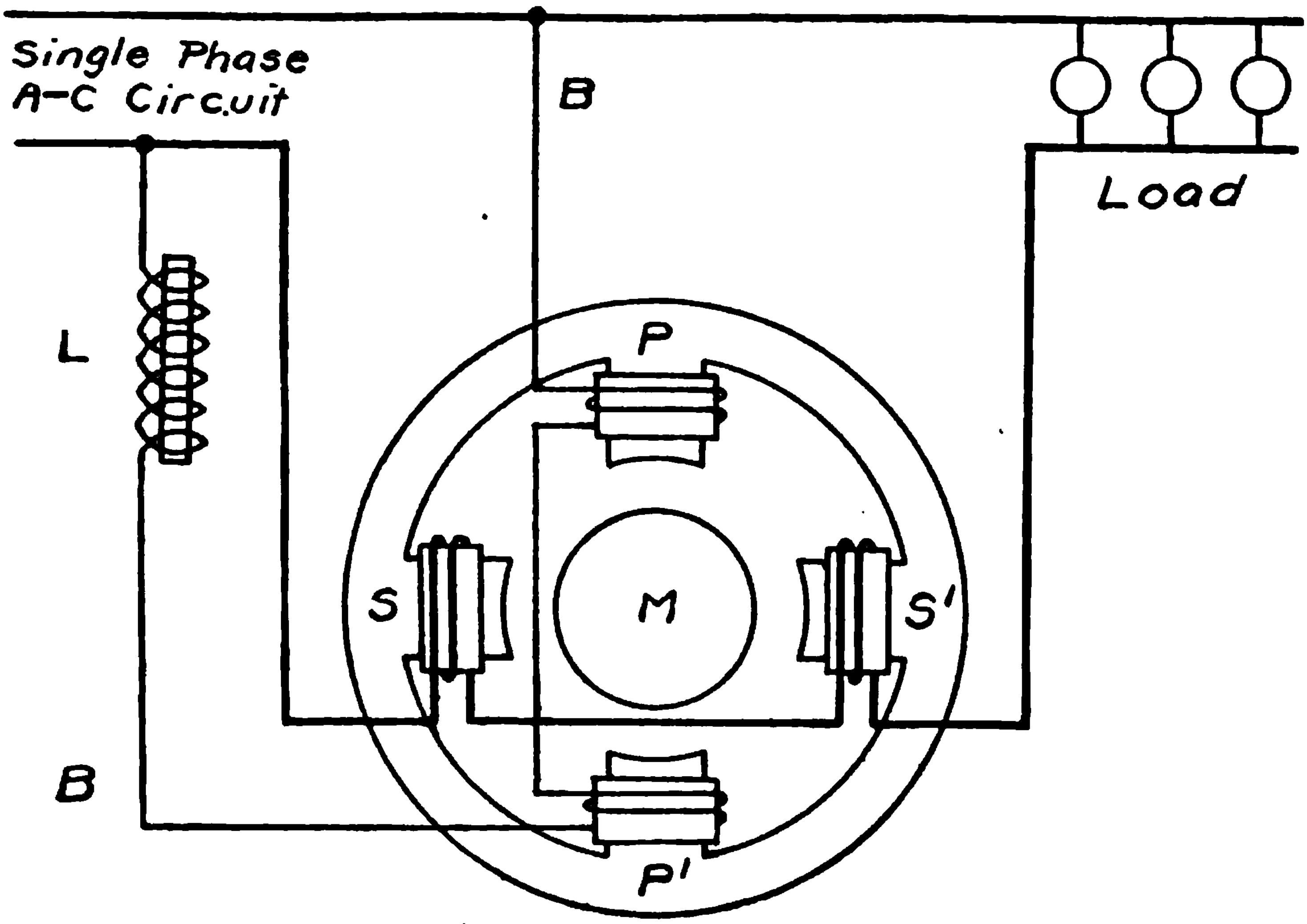


FIG. 90.—The Split-phase Method of Producing a Rotating Field Applied to Induction Watt-hour Meter.

Fig. 90. It will be noted that a single-phase alternating current circuit is employed, to which the coils are connected in a special manner as described.

The coils *P* and *P′*, which are wound with small wire, and an inductance coil *L*, are connected in series, forming the branch circuit *B* which is connected in multiple across the main circuit. The strength of the magnetic field produced by the coils *P* and *P′* will necessarily vary with the e. m. f. of the main circuit, and the field will have a large phase displacement relative to the impressed e. m. f., due to the inductance coil, the function of which is to lag the current in the branch circuit as nearly 90 degrees as possible. This cir-

cuit forms the potential circuit, or potential element of the watt-hour meter.

The coils on poles *S* and *S'* are wound with large wire and are connected in series with the main circuit and therefore with the load. In this arrangement a non-inductive load, or translating device, is used in place of the non-inductive resistance, *R*, previously mentioned. The strength of the magnetic field produced by poles *S* and *S'* will be directly proportional to, and will increase or decrease with the load being dissipated. Consequently there will be no magnetic flux when there is no current passing through the series, or main, circuit. This circuit forms the series circuit, or the current element of the watt-hour meter.

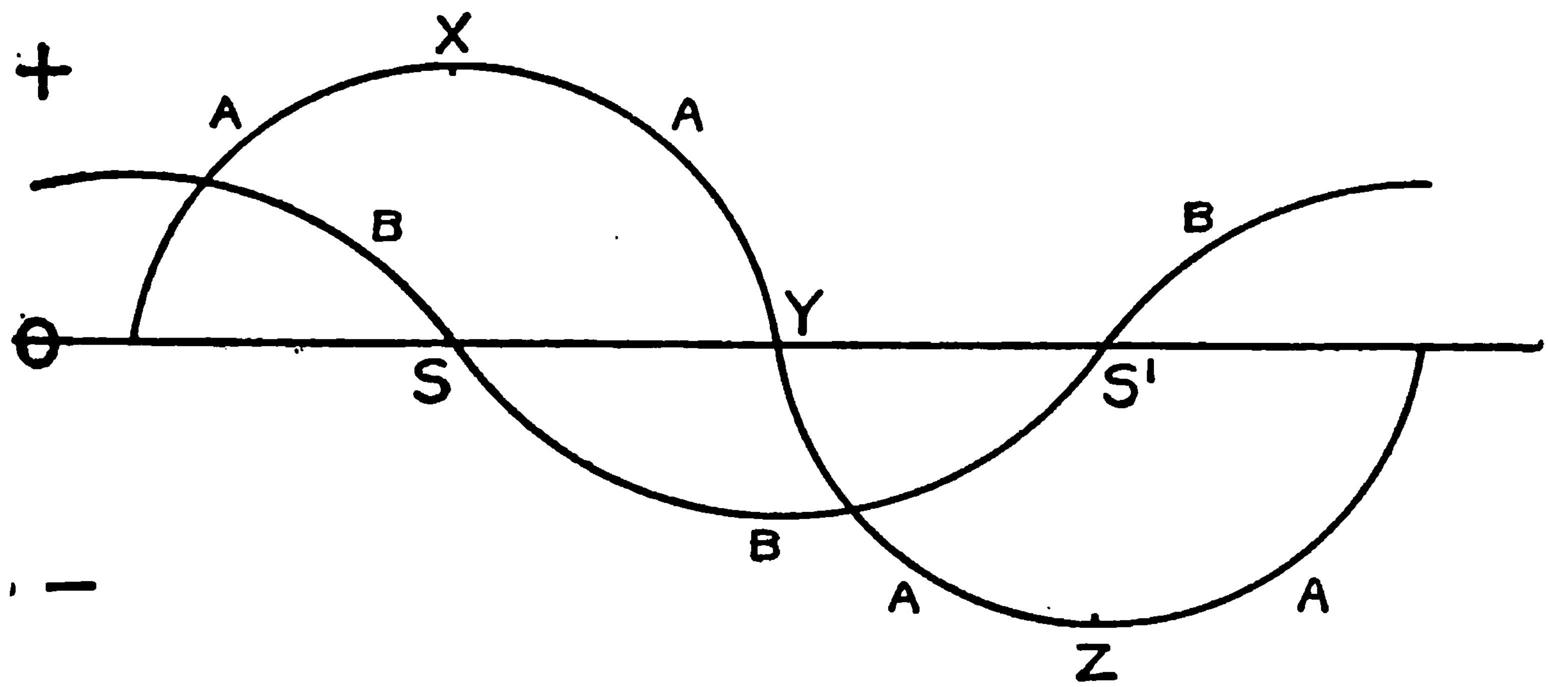


FIG. 91.—Current and Reactance e. m. f. Waves.

It is evident that as the current in branch circuit *B* is lagged so that a phase displacement occurs which approaches 90 degrees, and as the series load is non-inductive, producing practically no phase displacement of the field in poles *S* and *S'*, the combination of the two fields will produce a resultant, rotating, magnetic field and cause the rotor M to turn in the same direction as the progression of the field.

The arrangement of the poles *P* and *P'*, *S* and *S'* and rotor *M* as just described, and as shown in Fig. 90, has the appearance of the circuit design generally employed in the construction of alternating current induction motors, and it is obvious, that, in the design of an induction watt-hour meter for use in service, the arrangement of the magnetic poles with respect to the rotor, or moving element, would necessarily be somewhat different and would vary in the different designs of induction

watt-hour meters; nevertheless, the principle involved is essentially the same.

A single-phase induction watt-hour meter is practically a form of motor, the fields of which are produced by the application of a split-phase principle to an alternating current single-phase circuit. The magnetic poles are so arranged that the fields combine and act on a short circuited movable armature. **By the reaction of the eddy currents thus developed** and the rotating magnetic field established, a rotation of the moving element is produced. The addition of a suitable retarding device completes the electrical part of this meter. With this construction the number of revolutions of the moving element is

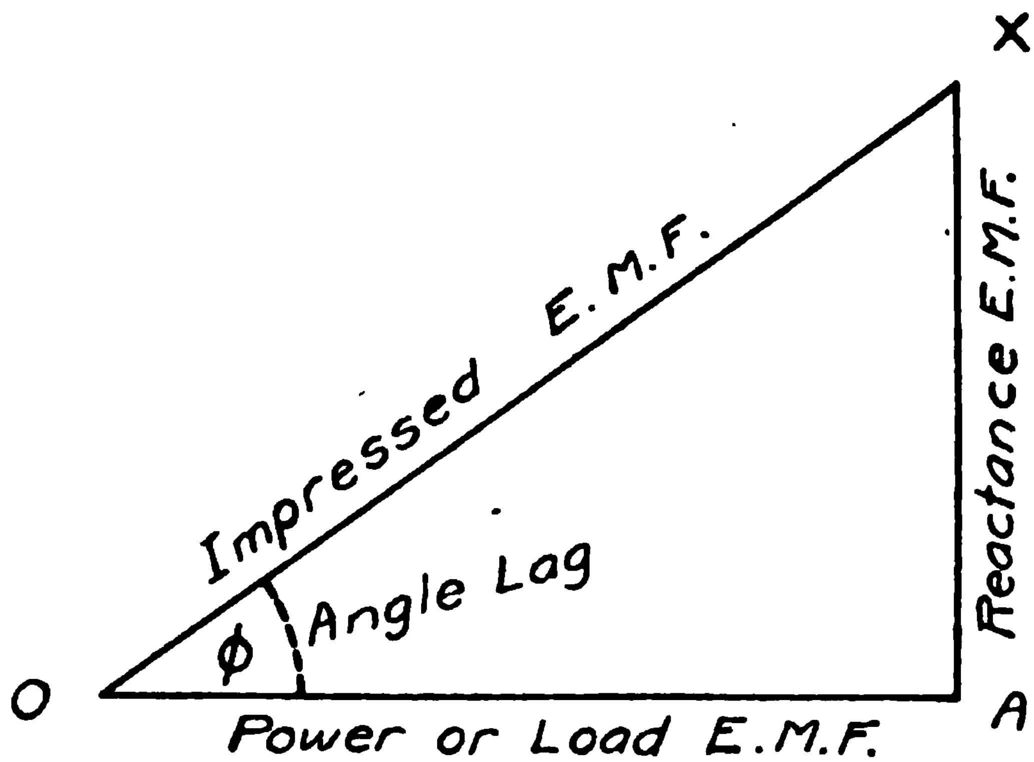


Fig. 92.—E. m. f. Vectors of an Alternating Current Circuit.

proportional to the energy units dissipated in the circuit, which is the function of an integrating meter.

A conductor carrying a current is surrounded with a magnetic field, and any change in the current will produce a corresponding change in the field. If the current is alternating, the magnetic field will change with each alternation, consequently the field will be continually destroyed and re-established.

An alternating current is represented in wave form in Fig. 91 in which curve *A* represents the power, or load, e. m. f. If the portion of the curve above the line *O* is considered as having a positive value and that portion below the line as having a negative value, the magnetic field is destroyed and re-established at the point *Y*, when the power e. m. f. is changing from a positive to a negative value (Chapter II).

When a field changes, or collapses, the magnetic lines cut the

conductor carrying the current and establish an e. m. f. in that conductor; that is, **the reactance e. m. f.** It will be noted that the magnetic field is changing at its greatest rate at the point *Y*, therefore the reactance e. m. f. will have its maximum value at that instant, as shown by curve B.

At the instant the power e. m. f. has a maximum positive, or maximum negative, value, represented by points *X* and *Z* respectively, there is no change in the magnetic field, consequently the field does not cut the conductor. The reactance e. m. f. is therefore zero at those instants, and the curve of reactance e. m. f. is shown as crossing the zero line at the points marked *S* and *S'*.

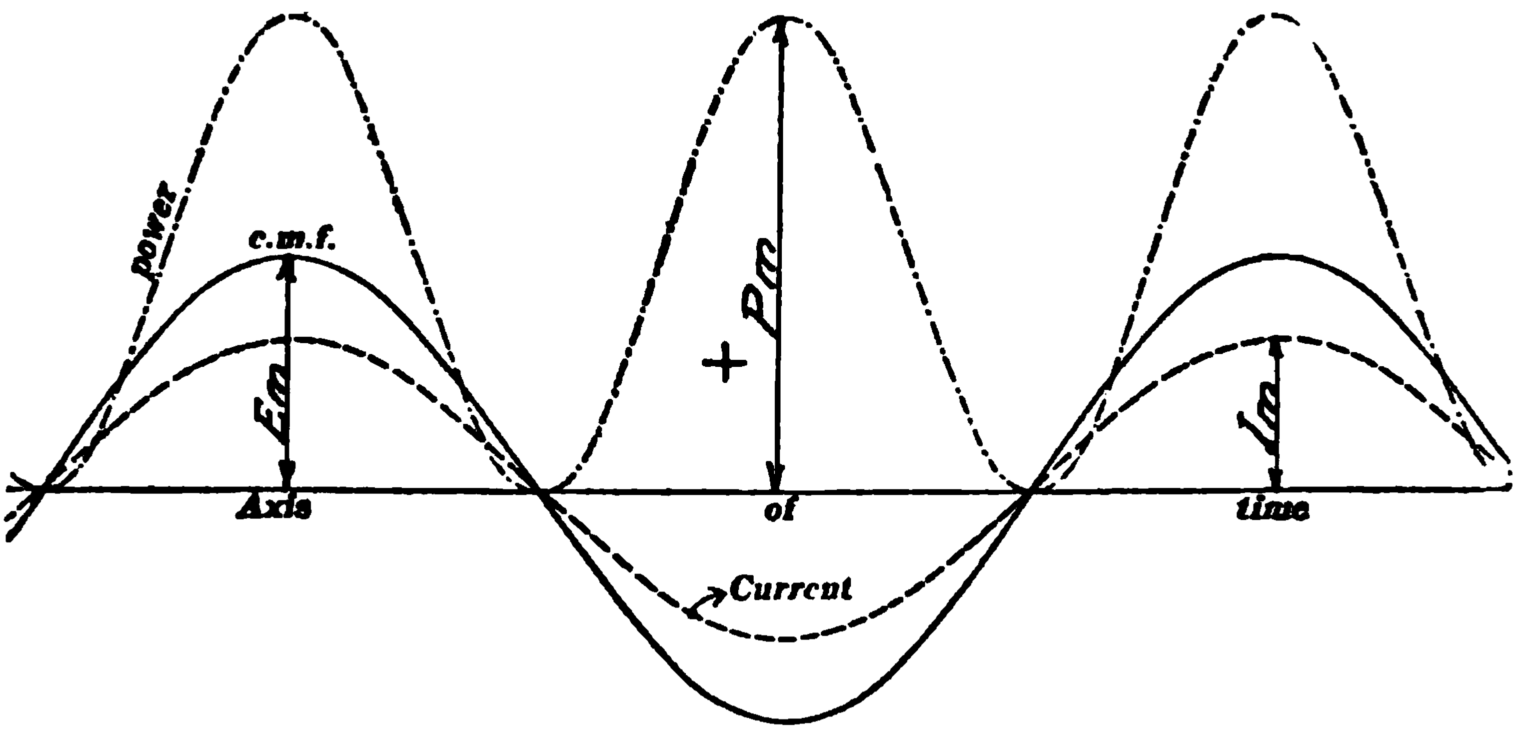


FIG. 93.—Relation of Power to Current and e. m. f. when ϕ is 0 Degrees.

It is evident then that curve *S-S'* represents the reactance e. m. f. of any circuit, and it is always 90 degrees behind with relation to the power, or load e. m. f.

A diagram of forces may be plotted to represent the relation of the various e. m. fs. as shown in Fig. 92.

The reactance e. m. f. component is plotted at right angles to, or 90 degrees from, the power e. m. f.

The power, or load, e. m. f. is the e. m. f. component that is useful in doing work, and is always in phase with the current in the circuit.

The impressed e. m. f. is plotted as the hypothenuse of the triangle, and is the e. m. f. required to be applied to the circuit to overcome the reactance e. m. f. and to give a power e. m. f. equal to the component shown.

The Greek letter ϕ represents the angle of lag between the impressed e. m. f. and the power, or load, e. m. f.

The power in the circuit, which is equal to the product of the power e. m. f. and the current, may be easily determined when the reactance component is zero, for then the impressed e. m. f., which is a measurable quantity, is in phase with the power e. m. f. When a reactance component exists, the impressed e. m. f. will not be in phase with the power e. m. f. As the current in phase with the power e. m. f. and the impressed e. m. f. are the measurable quantities, the angle of lag between the impressed e. m. f. and the power e. m. f., or current, must be taken into consideration. (See Chapter IV.)

In determining the true power in the circuit, the factors that enter into the calculation are:

W = the wattage, or power;
E = the impressed e. m. f.;
I = the current in the circuit (formerly symbolized, C);
ϕ = the angle of lag between the impressed e. m. f. and current.

The formula is:

$$W = EI \text{ cosine } \phi.$$
When $\phi = 0$,
then cosine $\phi = 1$;
therefore $W = EI$.

The true power and the apparent power are equal, and the reactance component equals zero, when the impressed and power e. m. f's. are in phase (Fig. 93).

When $\phi = 90$ degrees,
then cosine $\phi = 0$;
therefore $W = 0$.

The impressed e. m. f. and the power e. m. f. are then at right angles, and the reactance component is equal, and opposite, to the impressed e. m. f. (Fig. 94).

It is evident that the power in the circuit is a function of the angle of lag betweeen the impressed e. m. f. and the power e. m. f. or current, and when the phase displacement is 90 degrees the power becomes zero. Between the above conditions the power varies from maximum to zero (Fig. 95).

The torque of a watt-hour meter must become zero when the power in the circuit is zero, and as it has been proven that **the power in the**

circuit is a function of the cosine of the angle of the lag, and that the power becomes zero when the angle of lag is 90 degrees, therefore the torque must be proportional to the cosine of the angle of lag.

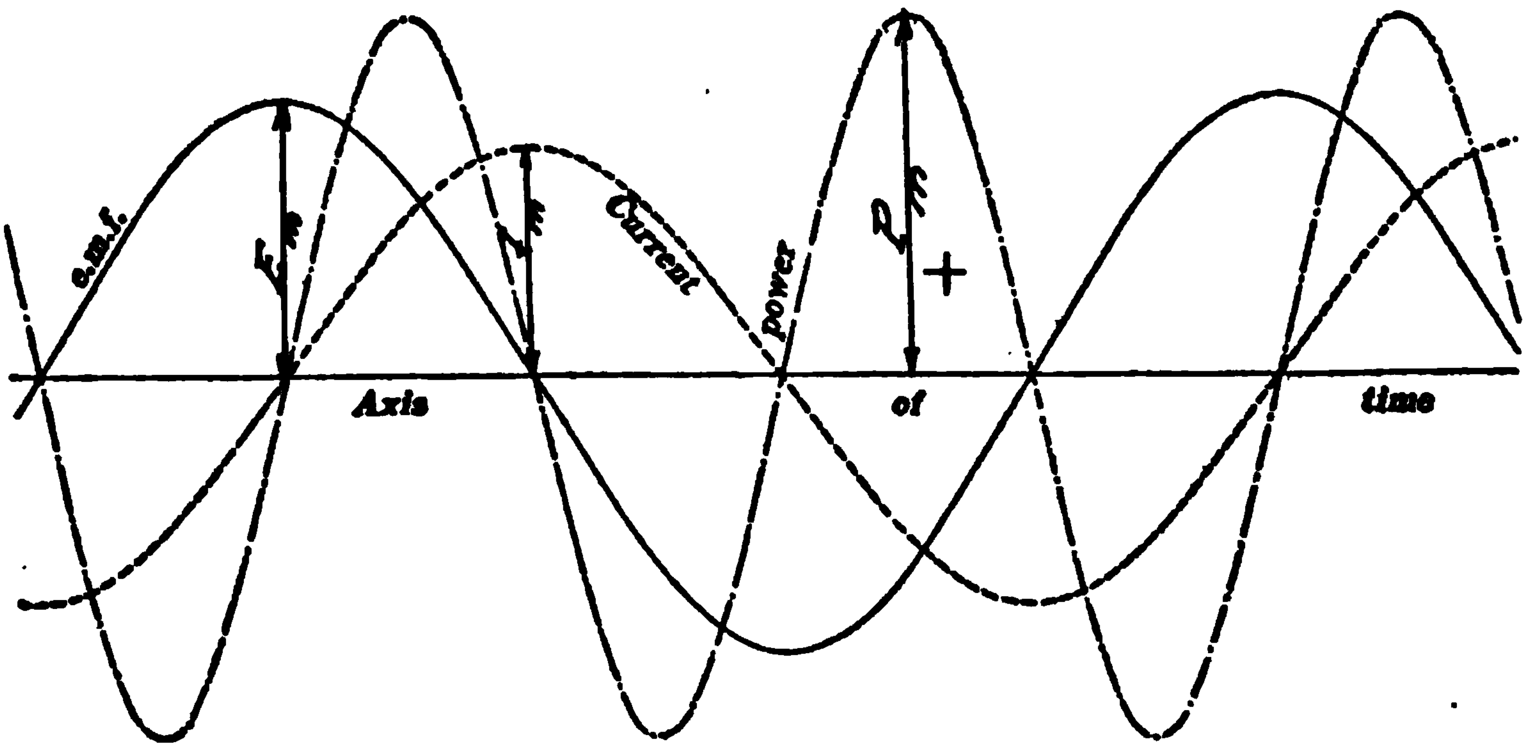


FIG. 94.—Relation of Power to Current and e. m. f., when ϕ is 90 Degrees.

It follows that, when the field of the potential circuit lags 90 degrees behind the impressed e. m. f. and the current in the series, or current, coils lags 90 degrees, there is a condition of no power in the circuit, and no

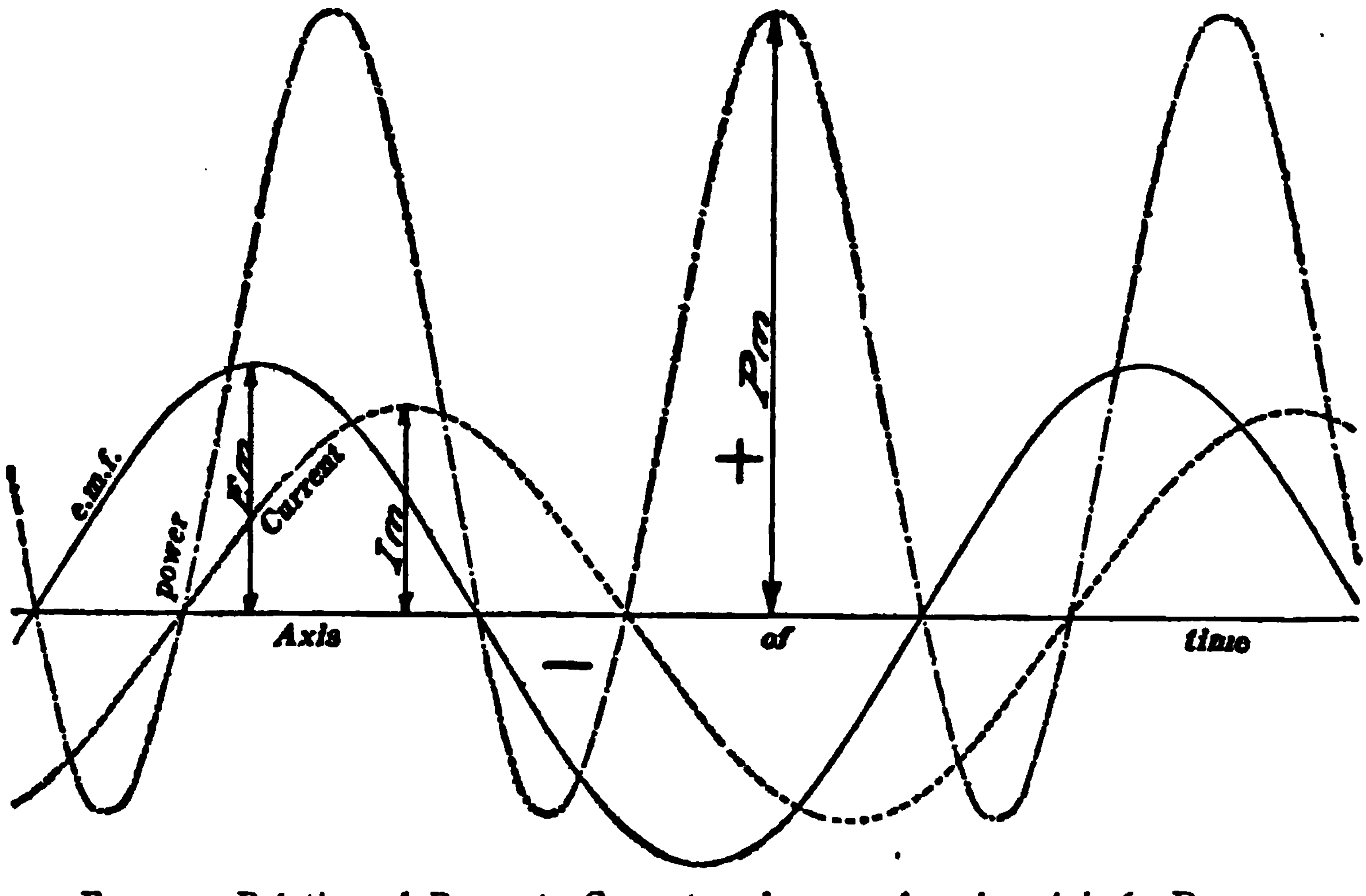


FIG. 95.—Relation of Power to Current and e. m. f., when ϕ is 60 Degrees.

torque to produce rotation in the meter exists, because the fields are then in phase and single phase relation obtains, as shown in Fig. 88. Application of this principle is made use of in testing, as explained in Chapter VI.

When a watt-hour meter operates on a non-inductive circuit, the reactance e. m. f. component of the circuit is zero and the power e. m. f. component coincides with the impressed e. m. f. The fields produced by the series coils and potential circuit of the watt-hour meter are displaced

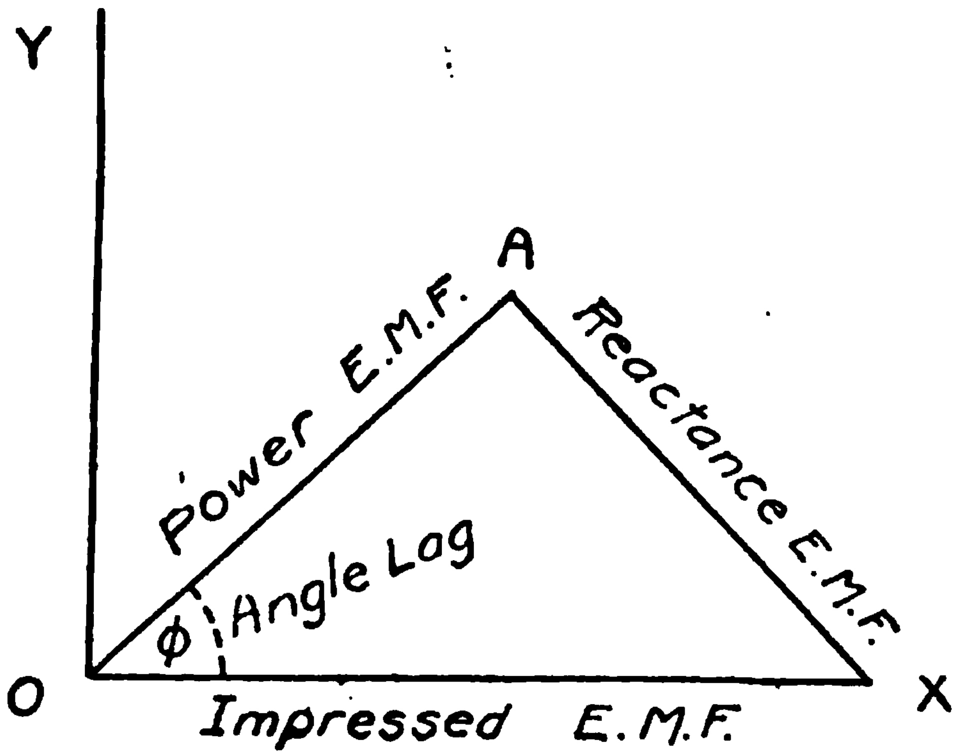


FIG. 96.—Alternating Current e. m. f. Vector Diagram.

90 degrees and consequently produce maximum torque for minimum apparent power.

In Fig. 96 the field of the potential circuit is represented by the position of the line *OY* and the impressed e. m. f. by the line *OX*, the phase relation being 90 degrees.

When a watt-hour meter is operated to measure the energy in a circuit containing inductance, the phase position of the power, or load, e. m. f. depends upon the reactance e. m. f. component of the circuit.

With an impressed e. m. f. of a given value, the greater the reactance e. m. f. component, the greater the angle of lag and the smaller the power, or load, e. m. f. component, as shown by the dotted lines. When the magnitude of the reactance component is sufficient to cause the power e. m. f. component to reach the 90-degree position, the field produced by the series coils and by the potential circuit of the watt-hour meter will be in phase with each other and therefore will produce no torque, or rotation, of the moving element of the meter.

A maximum torque, or rotating effect, is obtained when the series and shunt component magnetic fields bear a certain definite phase relation with each other, as described.

Referring to Fig. 97, diagram *a*, curve *X* represents the magnetic field produced by a single-phase alternating current and curve *Z* represents the field produced by a current from the same source. The field *X* is shown as having a greater strength than field *Z* and

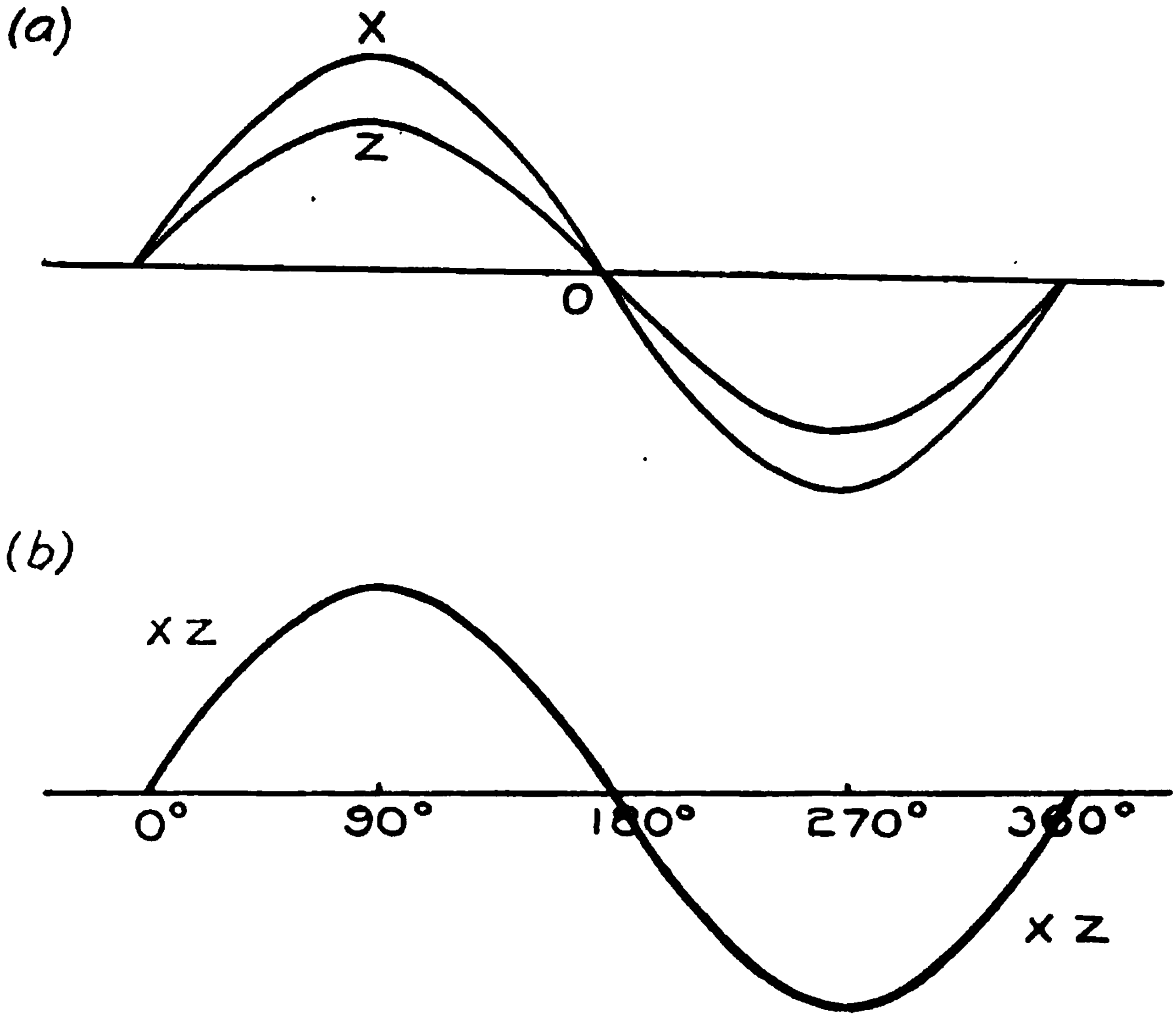


FIG. 97.—(*a*) Curves of Magnetic Fields for Synchronous Alternating Currents of *Different* Value. (*b*) Curves of Magnetic Fields for Sychronous Alternating Currents of the *Same* Value.

its curve therefore has a greater maximum value, but it is evident that when both fields have the same maximum value the curves representing them will be identical and the points will coincide, so that the curves will appear as a single curve as shown in diagram *b*.

It has been previously shown that magnetic fields produced by single-phase currents that are in phase will not combine and establish a resultant rotating field, but will simply alternate between the field poles. Hence, a torque to cause rotation of an armature will not exist.

By reversing the connections of the circuit that produces the magnetic field Z, the polarity of the field will be reversed with respect to field X. The field Z will then have a maximum negative value when the field X has a maximum positive value; both fields reaching the zero position O at the same instant. As the fields are equal

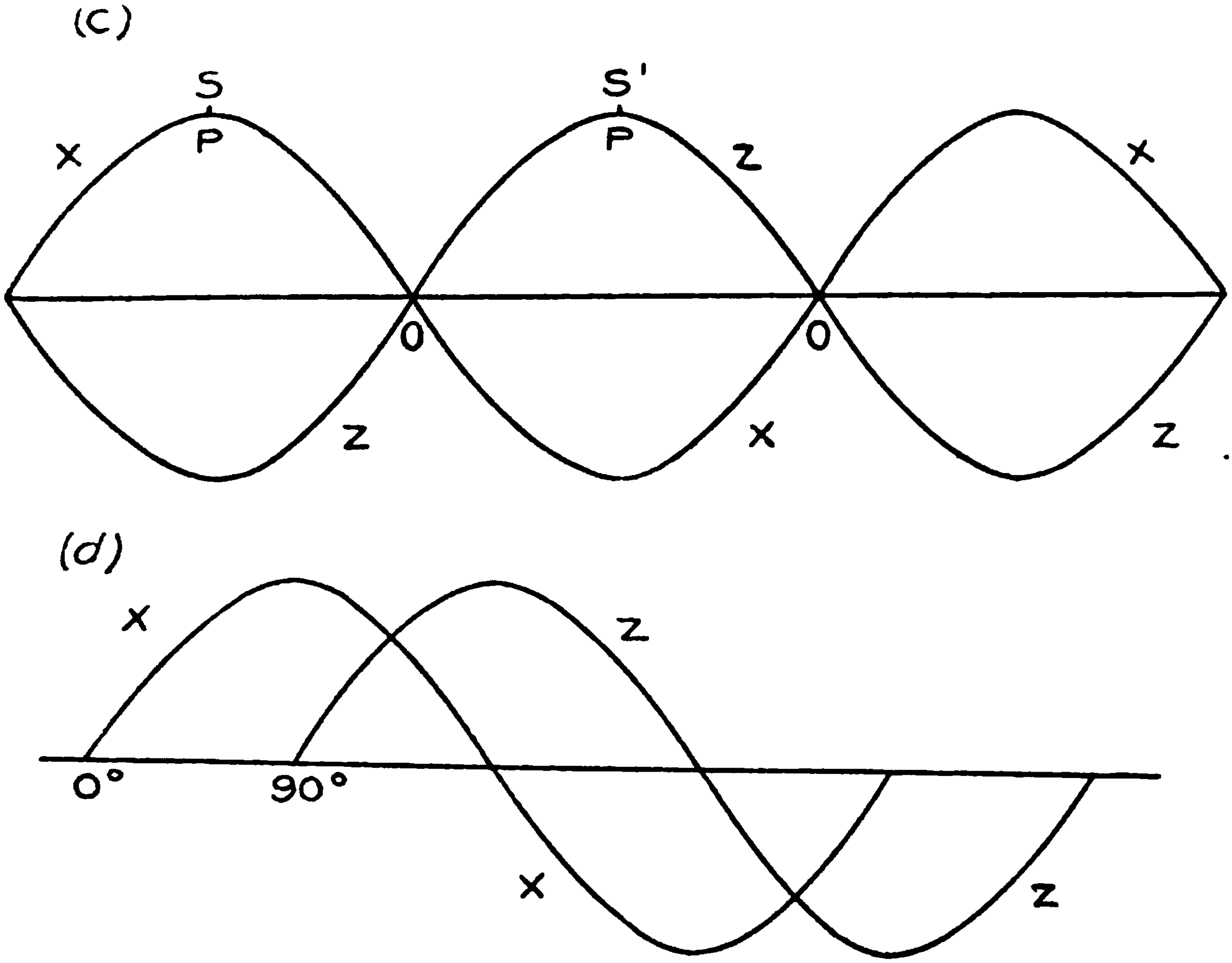


FIG. 98.—(*c*) Curves of the Magnetic Fields of Two Equal Alternating Currents in *Opposition*. (*d*) Curves of the Magnetic Fields of Two Equal Alternating Currents in *Quadrature*

and in opposition at every instant the result will be zero flux, consequently there will be no torque, or rotating effort.

When the magnetic field of Z is reversed what really takes place is that the curve Z, Fig. 98, diagram *c*, has shifted 180 degrees: that is, the point P is moved from the position S to S' and no torque results.

It has thus been shown that there are two positions exactly 180 degrees apart which produce no torque, and it has also been demonstrated that when the currents producing the flux are not in phase a torque exists; it is obvious, therefore, that there must be some intermediate

position between zero and 180 degrees that will produce maximum torque. It might be assumed that this point is midway between these extremes, or at the 90-degree position, shown in diagram *d*, and such is the case, for when the magnetic fields are in quadrature they have a maximum average value, and consequently produce maximum torque.

The magnetic fields that produce rotation of the moving element of a watt-hour meter are established by the current coils and potential coils; these fields being proportional to the main current and to the voltage of the circuit respectively.

On non-inductive loads the current coils connected in the main circuit produce a field that is practically in phase with the impressed e. m. f. The field of the potential coils, which are connected across the main circuit, is produced by the current, which is lagged in this potential circuit as explained above; therefore the field is displaced about 90 degrees with respect to the field of the main current circuit.

It is impossible to lag the current in the potential circuit exactly 90 degrees by means of an impedance coil, on account of the energy expended in overcoming the electrical losses; therefore the condition of maximum torque cannot be obtained by the split-phase method unless a special means of phase compensation is provided.

It is not essential that a phase displacement of exactly 90 degrees should exist between the magnetic flux of the current and potential circuits, when the load to be metered is non-inductive, as the current and voltage of the main circuit are then in phase, and under this condition a watt-hour meter with fields not in perfect quadrature will register with accuracy the energy consumed in the circuit.

When the load to be metered is inductive, a phase difference occurs between the current and voltage of the main circuit and the power in the circuit is then equal to the product of the current and voltage multiplied by the cosine of the angle of lag. The driving torque of a meter will vary with these factors, so that its speed will represent the power in the circuit only when there is an exact 90-degree displacement of the potential circuit flux from the impressed e. m. f. Therefore phase compensation to secure this relation is necessary, otherwise the watt-hour meter will register inaccurately on an inductive load.

Various methods have been devised to secure a condition where the magnetic flux produced in the potential circuit is in exact quadrature with the e. m. f. This is termed lagging the meter.

One of the methods available is to lead the flux of the current coils by dividing the main current circuit in two parts; one circuit

having practically no inductance and the other being highly inductive and connected in reverse relation to the first. By adjusting the two coils a resultant magnetic field is produced by the series coils which leads the field of the potential circuit by an angle of 90 degrees.

Another **means employed to obtain the proper phase relation** in the potential circuit is to arrange in parallel a non-inductive and an inductive resistance and to connect an impedance coil in series with these resistances; the whole being connected across the main circuit. The impedance coil alone will lag the current nearly 90 degrees, but by dividing the current in the impedance coil by means of resistances, a resultant shunt flux is produced which has a 90-degree phase displacement with respect to the impressed e. m. f.

While the two methods described are used in European watt-hour meters, they are not at present used by American manufacturers.

The generally used method consists of connecting an impedance coil, either alone, or in series with an additional coil, across the pressure circuit so as to produce an initial phase displacement as near 90 degrees as possible.

Short circuited secondary windings, or coils, are then arranged in such relation with respect to this potential circuit that the potential winding acts as a primary to the secondary coil. The magnetic field of the potential circuit produces currents, and consequently fields, in the secondary coil which combine to produce a field having an additional lag. This may be adjusted to have the proper 90-degree phase relation.

Watt-hour meters of the motor type are provided with a **magnetic brake,** which is necessary in order to obtain a speed directly proportional to the power.

When a conductor that is part of a closed circuit is moved across a magnetic field, an e. m. f is generated in it that is proportional to the speed. A current will flow that is proportional to the e. m. f. and inversely proportional to the resistance. If the resistance be kept constant, the current will be proportional to the e. m. f. generated and is therefore directly proportional to the speed.

In the magnetic brake a constant field is supplied by a permanent magnet. Between the magnet poles revolves a copper, or aluminum, disk or cylinder, which is fixed on the shaft of the moving element. The conductor is therefore directly under the poles, and the disk provides a closed circuit of constant resistance.

The action may best be understood by referring to Fig. 99. The direction of the magnetic flux is downward from *N* to *S*, cutting the disk which rotates, as shown by the arrow *A*. This causes currents

to be generated in the disk having a direction shown by the arrow *B*. These currents divide and return through the part of the disk where no current is being generated, as shown by arrows *C*.

The eddy currents generated produce poles proportional to their strength, as shown by N and S on the upper side, and the corresponding poles (not shown) are established on the under side of the disk. Pole *N* repels N and attracts S, and *S* correspondingly repels

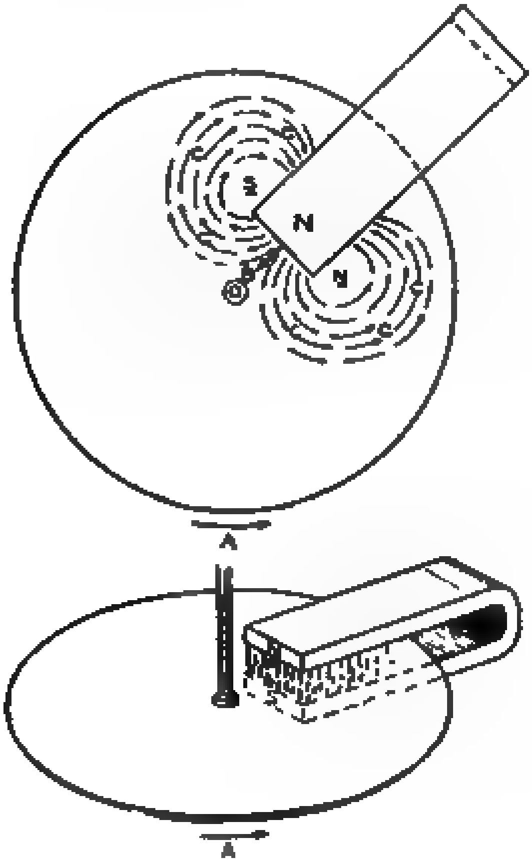


FIG. 99.—Eddy Currents Induced in a Disk Rotating in a Magnetic Field.

FIG. 100.—Turning Action Between Two Coils.

and attracts the poles not shown. As both of these attractions and repulsions oppose the motion of the disk, according to Lenz's law, a magnet placed in this manner embracing the non-magnetic disk will create a drag proportional to the speed of the disk.

Watt-hour meters are provided with a magnetic brake, consisting of a permanent magnet, or magnets, and a copper, or aluminum rotor which revolves between the magnet poles.

The speed of the rotor is generally regulated by adjusting the magnets in, or out, from the center of the disk; or by adjusting them to embrace more or less of the moving element, thus changing the

amount of flux cut. Another method of speed regulation is to provide the magnets with an adjustable iron armature placed over the poles, so as to divert, or shunt around the rotor, more or less of the magnetic flux.

Iron shields are sometimes provided to protect the magnets from abnormal magnetic flux, generally due to short circuits on the line.

Alternating current induction type watt-hour meters all depend upon the same basic principles for their operation, and in general differ only in the manner in which the principles are applied and in the details of construction. See Chapter XVI.

Current and potential windings are provided which are arranged in such relation that they produce a rotating magnetic field by the split-phase method, which cuts a closed-circuit secondary and causes it to rotate.

The closed secondary consists of a disk or cup-shaped rotor, made of aluminum, which is mounted to rotate through the magnetic fields and also, simultaneously, between the poles of permanent magnets which produce a retarding effect and serve as a regulating device.

The series, or current, winding consists of two practically non-inductive current coils, each having a few turns of comparatively large wire. These coils are wound in opposite directions and connected in series with the main circuit, or load.

The current coils are generally mounted on laminated iron cores, or poles, which project directly toward the rotor, thus directing and concentrating the magnetic flux.

The potential windings consist of potential and impedance coils, which are wound with a great number of turns of fine wire and mounted on laminated iron cores to produce a large phase displacement of the field.

Some potential coils are designed with sufficient impedance to be connected directly across the main circuit; others are designed to be connected in series with a separate impedance coil. In the latter case the potential coil is mounted on a separate laminated iron core which provides poles for concentrating the magnetic field that acts directly on the rotor.

Phase compensation for securing an exact 90-degree phase displacement of the potential circuit field is accomplished by an arrangement of auxiliary windings, or coils, and by closed-circuited secondaries used in combination with the coils of the potential circuit.

Compensation for static friction is accomplished by the use of closed-circuited loops, or secondaries, and by auxiliary coils that are arranged in such relation with respect to the field of the potential

coils that they produce an unbalanced or unsymmetrical condition of the potential field, thus establishing a slight rotating field effect. Provision is made for regulating the magnitude of this effect, generally by varying the position of the secondaries.

Friction compensation is sometimes obtained by placing around the potential circuit field core a movable copper turn, or closed, secondary. The turn is made to fit closely over the lower end of the core of the potential circuit field core and has internal dimensions large enough to permit moving it horizontally either to the right, or left.

The effect of the closed secondary turn is practically the same as the effect produced by the shading ring, or coil, on the pole of a single-phase induction motor.

Assuming that the secondary turn is not present, it is evident that with current in the potential circuit and no current in the series circuit, the potential circuit field would be magnetically balanced. Introducing the secondary turn centrally with respect to the magnetic field would not alter the balanced condition.

Moving the turn in either direction would produce a slight unsymmetrical condition of the field, which would result in a torque. This unbalanced condition is due to the reactive effects of the field of the secondary, which would then be greater on one side of the potential circuit field pole. This produces the effect of a slight rotating field. The turn may be adjusted to such a position that the unbalanced field will produce just sufficient torque to overcome the friction of the moving element.

An extreme unbalance of this nature under the conditions of no load in the series coil, will produce a torque sufficient to cause creeping (Chapter VII).

The electromagnetic action between two coils and the method in which this **principle** is **utilized and applied in** the construction of **commutator type of motor watt-hour meters** is illustrated in the following description.

When two coils, as shown in Fig. 100, are supplied with current, a magnetic field will be established by each coil, and the direction of the fields will depend on the direction of the current in the coils. Magnetic poles will be established which will produce an attraction, or repulsion, depending on the relative polarity and position of the coils. When one coil is movable and the other is stationary, the movable coil will assume such a position that its magnetic field will be in the same direction and will coincide with the field produced by the stationary coil. The principle of the magnetic action described is applied in commutator motor watt-hour meters in the following manner (Fig. 101).

The current coils produce a magnetic field having a definite direction, and, as the coils are in series with the main circuit, the strength of this field will be proportional to the main current. They are arranged sufficiently close together to produce the effect of a single coil, and practically surround the armature.

The armature is of the closed-coil type, with taps from the winding to the commutator segments, and as the current enters through but two taps which are connected to diametrically opposite points, the armature circuit is virtually divided into two parts which are in

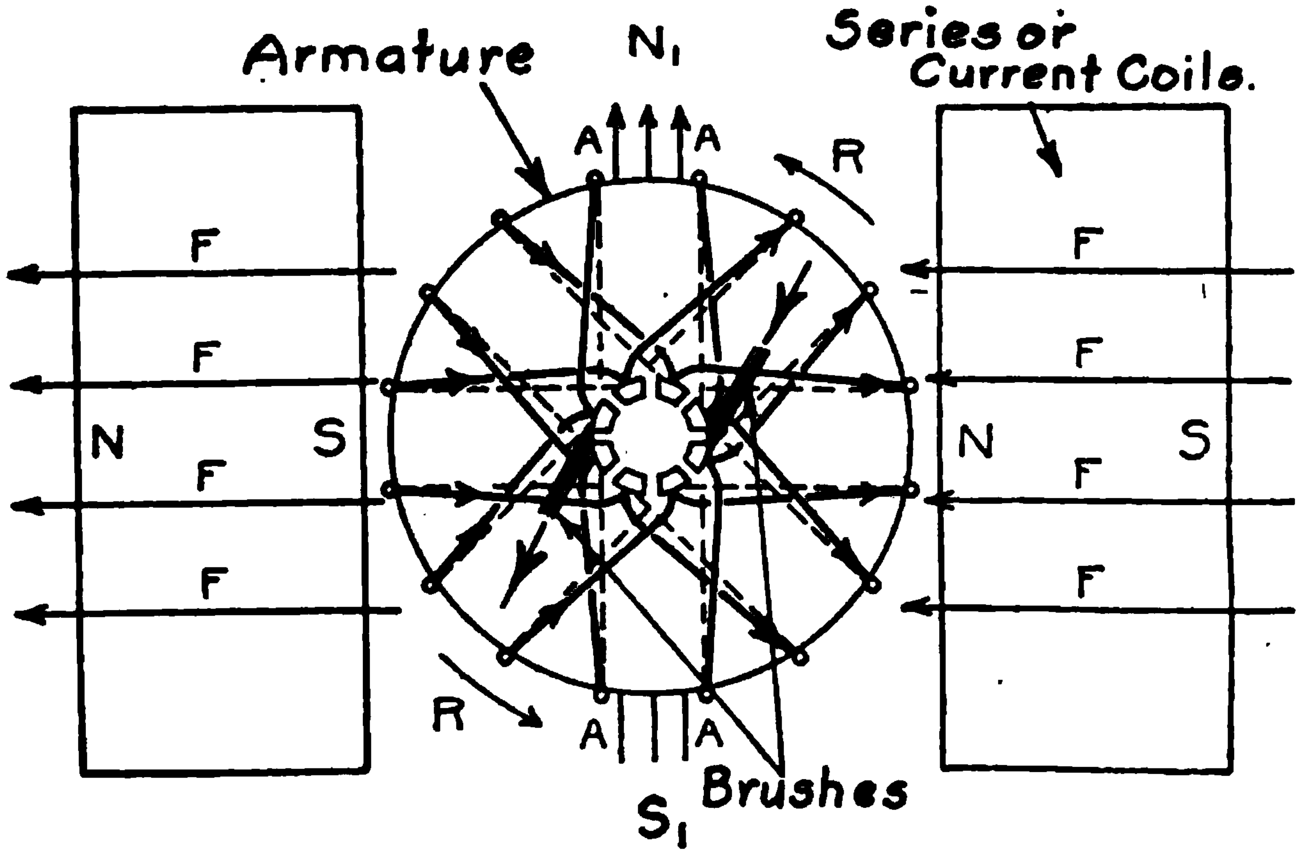


Fig. 101.—Magnetic Fields Established in a Fundamental Commutator Motor Watt-hour Meter.

parallel. When the current enters through the brushes and commutator it will therefore pass in a downward direction in one-half of the armature and upward in the other half.

The magnetic field established by the armature coils will be an equivalent, or resultant, field having a general direction, which will depend on the position of the armature coils with respect to the commutator segments and to the position of the brushes on the commutator. The strength of the armature field will depend on the current in the armature circuit and will be directly proportional to the e. m. f. of the main circuit.

In Fig. 101 is shown the direction of the magnetic field established by the current coils, as indicated by the arrows marked *F*. The polarity of the coils is indicated by the letters *N* and *S*.

By virtue of the relation between the armature coils, commutator

segments and brushes, the general direction of the armature field is practically at right angles to the field of the current coils, as shown by the arrows marked *A* and the poles *N'* and *S'*. For demonstration, only the direction of the equivalent armature field is indicated.

The magnetic action between the two fields produces a torque that causes the armature to turn and endeavor to assume such a position that its field will coincide with the field produced by the current coils. When the magnetic poles are as shown in the diagram, the direction of rotation will be as indicated by the arrows *R*, the magnetic pole *S* of one field coil attracting the armature pole *N'* and repelling the pole *S'*, while the pole *N* of the other field coil attracts the armature pole *S'* and repels the pole *N'*.

An armature having but one coil and without a commutator would turn only until the direction of its magnetic field was the same as the field produced by the current coils and then it would stop. However, an armature as constructed in practice has a sufficient number of coils connected to an equal number of commutator segments, so that when the armature is turned a small amount, another set of commutator segments will come under the brushes and again establish a field approximately at right angles to the field of the series coils. When this condition is again established, a turning effort, or torque, is again produced, causing the armature to turn until another set of commutator segments come under the brushes, and so on. The magnetic field of the armature will therefore always be established in practically the same general direction with relation to the field of the current coils, thus causing a continuous rotation.

The torque exerted on the armature is proportional to the product of the strength of both the current coil and armature fields and is therefore proportional to the product of the current and the voltage of the main circuit, or to the actual power in watts.

Watt-hour meters of the commutator type, in general, consist of three essential parts, the motor, the brake, or retarding device and the registering mechanism (Fig. 102).

The element of the continuous current watt-hour meter causing rotation is, as will be seen, an electric motor of the shunt type, which, being without iron in its fields and armature and rotating at a very slow speed, has little, or no, counter-electromotive force. Its armature current, therefore, is independent of the speed of rotation, and is constant for any definite potential applied at its terminals. The torque of this motor being proportional to the product of its armature and field currents, must vary directly as the energy passing through its coils to the loaded circuit. In order, then, that the meter

shall record correctly, it is necessary only to provide some means for making the speed proportional to the torque. This is accomplished by applying a load, or drag, the strength of which varies directly as the speed. This leads to a brief consideration of the generator element.

The electromotive force induced in a conductor passing through a field of constant strength is proportional to the number of magnetic lines of force cut in a given time; therefore, if the resistance of the conductor remains constant, the drag is proportional to the speed. A metallic disk is directly connected to the meter armature by means

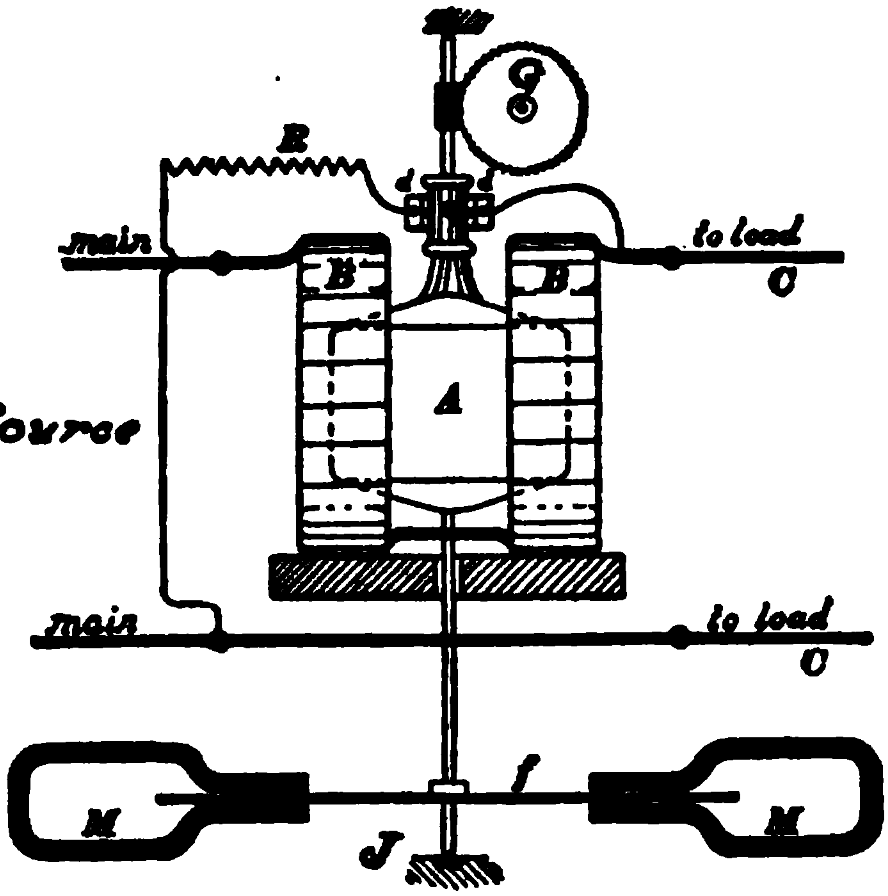


FIG. 102.—Diagram of a Commutator Type of Watt-hour Meter. A, Armature; B, Current Coils; C, Leads; d, Brushes; e, Commutator; f, Disk; G, Recording Mechanism; J, Bearing; R, Resistance and Compensating Coil.

of a vertical shaft and, passing between the jaws of permanent magnets with field of fixed strength (Fig. 102), constitutes the second necessary element of the watt-hour meter.

The resultant torque exerted on the moving element of a commutator motor type watt-hour meter is due to the superimposition of the effects of the instantaneous values of the current and potential and is, therefore, proportional to the instantaneous products of these values. It, consequently, records the actual energy, or true watts, passing in the circuit whether supplied with alternating or continuous current and regardless of power-factor, although it is generally used on continuous current circuits (Chapter XVIII).

A means of combining all the instantaneous values of energy is found in the registering mechanism, or register, the third element of the watt-hour meter. This is a revolution counter calibrated, by means of the register constant, in the proper energy units, for which purpose the kilowatt-hour has now been standardized.

The motor, as generally constructed, requires the following principal parts, which are necessary for the arrangement of the electrical circuits (Fig. 102): The main current coils, armature, resistances, compensating coil, shaft, commutator and brushes. The electrical circuits, essential for the operation of the motor, are the current, or series, circuit and the potential circuit, both of which are constructed without iron, except in special types.

The current circuit usually consists of two, or more, stationary coils, having a few turns of comparatively large wire wound in a circular, or rectangular, form. These coils are mounted parallel, in close relation, so that they practically surround the armature, which is mounted to rotate centrally within them. The current coils are connected in series with the main, or loaded, circuit, and the total current passes through them in a direction that will produce magnetic fields that coincide. For exceptions, see descriptions of shunted types of watt-hour meters, Chapter XVI.

A single current coil is sometimes used, having the armature placed centrally within the field.

The potential circuit consists of an armature, a resistance and a compensating coil, all of which are in series and connected directly across the main circuit.

The armature is generally of the closed-coil type, having a lap winding consisting of several coils, usually eight, as shown in Fig. 101. These coils are made of fine wires and are wound upon a light non-magnetic frame, which insures rigidity and serves as a means of mounting to permit rotation. Loops are made in the winding, serving as taps to the coils, and are connected to a small commutator, with which the armature is mounted on the shaft.

An armature of the open-coil type is sometimes used, consisting of three coils symmetrically arranged around the shaft, which are connected to a three-part commutator. The principle involved in producing rotation is practically the same as in a closed-coil armature.

Armatures are made in either ball, or cylindrical, shapes, so as to conform to the shape of the current coils and to properly occupy the space within the enclosure of the coils, so as to be cut by as much of the magnetic flux as possible.

The armature, commutator and disk for the magnetic brake are mounted on the same shaft, which rotates vertically, being supported at the bottom by a cushioned jewel bearing and at the top by a small guide-pin bearing.

The brushes serve as conductors for the current to enter the armature through the commutator. For two-pole, lap-wound armatures the brushes span one-half the commutator segments, for four-pole, wave-wound armatures one-quarter, and for three-coil armatures the span must be nearly two-thirds.

Commutators are usually constructed of small silver segments of a number equal to the number of coils in the armature and have a small diameter to reduce the moment of rubbing friction of the brushes.

The resistance is used to reduce and limit the current in the potential circuit so that small wire can be used in the armature winding. This permits the use of a light and compact armature with the necessary ampere turns to produce the desired strength of field. The resistance also reduces the voltage drop across the armature and indirectly diminishes the deteriorating effect of sparking at the brushes, should any occur. The resistance must have no inductive effect on the armature, or field, circuits, and it is generally constructed of fine wire wound upon cards, spools or tubes, which are mounted either within the meter, on the back of the meter base, or in a suitable box supplied as a separate unit. Another method of construction is to wind the resistance and friction compensator into a single coil, the principle of which will be subsequently described.

A certain amount of frictional resistance exists in every watt-hour meter, consisting principally of the friction of the bearings, registering mechanism and of the brushes on the commutator. This friction makes it difficult to obtain a speed of the disk, on light load, that is proportional to the energy consumed. In order to produce the least departure from the straight-line law, it is necessary to compensate for the existing and subsequent friction.

An auxiliary winding, or friction compensating coil, consisting of a number of turns of fine wire, is connected in series with the potential circuit and is placed in the same relation with respect to the armature as the main current coils. The auxiliary winding establishes a magnetic field, having a constant strength, which depends on the number of turns in the coil and on the current in the potential circuit. The polarity of the auxiliary coil is essentially the same as that of the current coils and produces just sufficient constant torque to overcome the friction.

As the friction does not always remain constant, several methods

are employed to vary, and adjust, the strength of the field produced by the compensating coil.

The effect of the field of the auxiliary winding is regulated by mounting the coil on an adjustable bracket, so that its distance and position with respect to the armature may be altered; or it is varied by making the coil stationary and regulating the strength of the current by shunting it, or by changing the number of effective turns in the winding.

The adjustable coil is constructed to pass within the windings of the current coil, so as to permit adjusting to a position very near the armature. A type of adjustable coil is made which has sufficient resistance to be connected directly across the circuit. This coil is virtually constructed in two sections, which are wound in opposite directions, each section having a different number of turns. The fields produced tend to neutralize, but as one section has a greater number of turns its field will predominate, therefore the effective field will depend directly on the difference between the number of turns in the two sections.

The field produced by the stationary type of coils is sometimes varied by shunting the coil with a resistance. An adjustable contact is provided, which may be connected to various taps to alter the value of the resistance. Stationary coils used for friction compensation are provided with taps connected to different turns of the coil. The taps are connected to contacts on a suitable multipoint switch, which is adjusted to vary the number of effective turns, in order to produce the desired strength of field.

The principle employed in the design of an astatic **multipolar type of watt-hour meter** is shown diagrammatically in Fig. 103. The current coil are so wound and connected that each coil establishes a separate field having opposite polarities, as shown, the coils being arranged sufficiently far apart so that the fields do not neutralize each other.

A four-pole closed-coil drum armature with a wave winding is provided, which establishes fields having polarities as shown.

Rotation of the armature is produced by the attraction and repulsion of the fields, as indicated; the north poles of the current coils repel the poles N' and N^2, and attract the poles S' S^2, established by the armature coils.

All **mercury motor meters** are based upon the principle that when a current of electricity is passed radially across a copper, or aluminum, disk immersed in mercury, and the path along which the current flows is subjected to the field of a strong magnet, rotation of the disk is produced. The reaction between the field of the current in the disk and the field of the magnet produces the rotation of the disk. This, of course,

is the fundamental basis upon which any electric motor operates, and the manufacturers of mercury motor meters have simply utilized this principle with modifications and additions.

In general, therefore, we may say that any mercury motor meter consists essentially of a rotatable cylinder, disk, or motor element, partly, or totally, submerged in mercury so that current can be led in and out from the moving element by the mercury acting as a contact-maker, fixed metallic contacts of one form or another being set in the walls of the chamber containing the mercury and the disk. An electromagnet properly set with respect to the disk or armature, will,

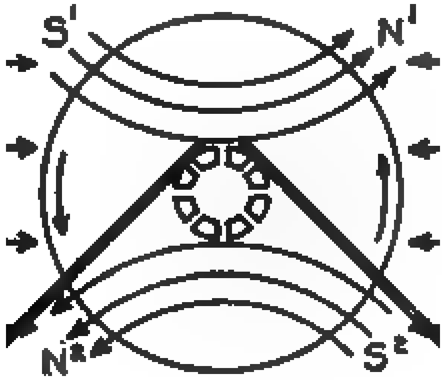


Fig. 103.—Astatic, Multipolar Motor Watt-hour Meter, with Four-pole Armature and Opposing Fields.

when energized, cause rotation of this armature, and this rotation may be made proportional to kilowatt-hours. This principle is adaptable either to continuous or alternating current, according to the construction employed.

Electrolytic meters depend on the chemical effects of electricity, manifested by the decomposition of a solution by the passage of an electric current through it. They are of the ampere-hour class and suitable for use on continuous current circuits only.

There have been many applications of this principle in different types of meters. The basic principle of one type is that the passing of a current of electricity through a volume of water decomposes the water into its constituent parts, and this decomposition is directly proportional to the volume of the current, one ampere-hour decomposing .3359 grams of water. Therefore, if a current is passed through a volume of water contained in a properly graduated tube, the change in the volume of

water in a given time will determine the amount of current supplied, as indicated by the graduated scale. The Bastian meter is of this type (Fig. 104).

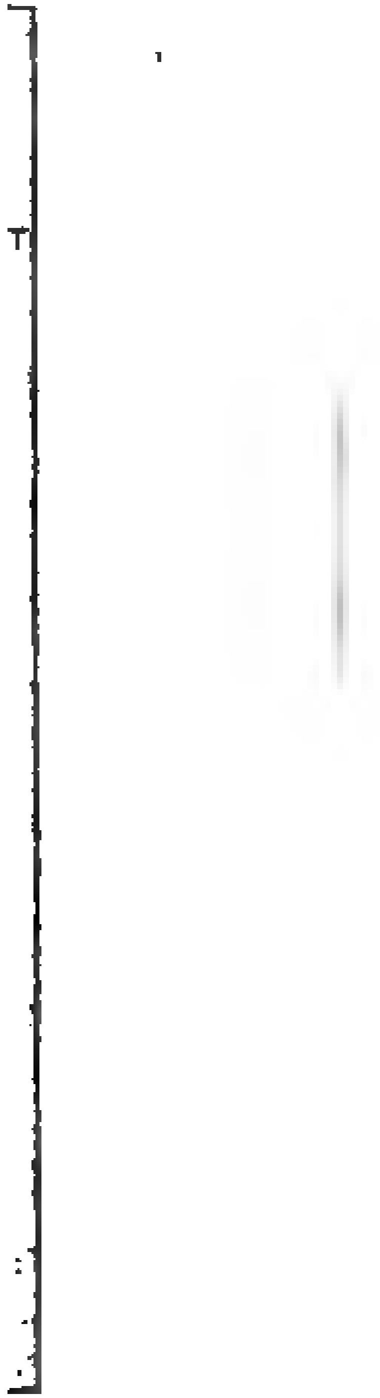


Fig. 104.—Helios, Bastian Electrolytic Meter.

Another type of meter depends upon the principle that one ampere-hour of current passing between zinc plates immersed in a solution of a salt of this metal, will remove from one plate and deposit on the other

1,224 milligrams of zinc. The amount of current passing in a circuit can consequently be measured by shunting a certain portion of it through a cell containing zinc plates in a solution of zinc sulphate and weighing

Fig. 105.—Edison Chemical Meter.

the positive plate to determine the amount of zinc transferred. The Edison Chemical meter was of this class. Fig. 105 is an internal view of a three-wire meter of this type, and Fig. 106 shows the connections.

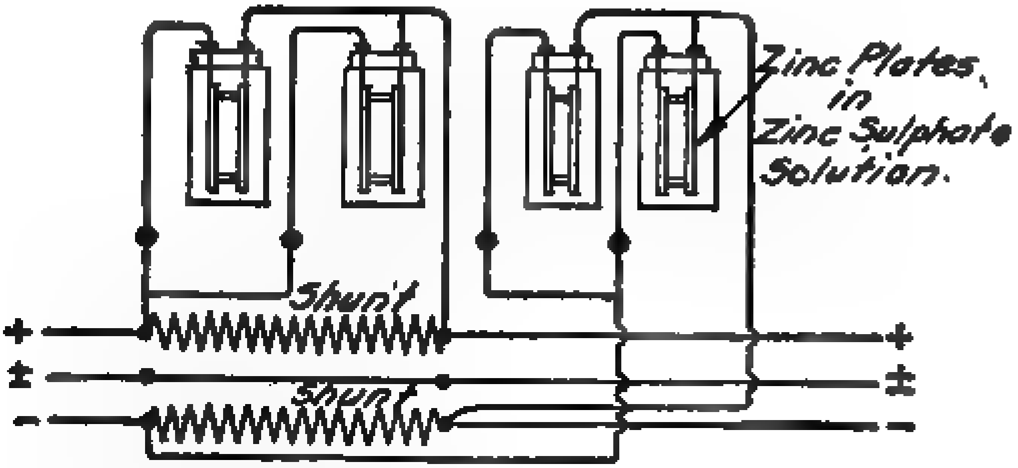


Fig. 106.—Connections for Edison Three-wire Chemical Meter.

In still another type, the passage of current causes a transfer of mercury through a solution of that metal on to a platinum cathode; as the deposit will not amalgamate with the platinum, it drops off into a tube so graduated as to indicate the amount of current which has passed. The Wright Electrolytic meter is an example of this type.

CHAPTER IV

THE MEASUREMENT OF ELECTRICAL ENERGY

CHAPTER IV

The Measurement of Electrical Energy

The commercial measurement of electricity depends upon the following units which have already been defined:

The **ampere,** the unit of current volume; the **volt,** the unit of electromotive force, or potential; the **watt,** the unit of electrical power.

From these we derive the **ampere-hour,** the **watt-hour** and the **kilowatt-hour,** which include the elements of both quantity and time, and are, consequently, adapted to the measurement of the supply of **electrical energy** for commercial purposes.

The watt-hour or its multiple, the kilowatt-hour, is the unit in general use in this country for the commercial measurement of electricity, and the energy supplied in a circuit is measured directly by means of a **watt-hour meter,** the principles of which have been described in Chapter III. The requirements placed upon a watt-hour meter as regards its operation are probably the most stringent exacted from any measuring device, and yet, when properly cared for, its accuracy is without doubt equal to that attained in the measurement of any other commodity in everyday use.

The ampere-hour may be used as a basis for computing the watt-hours, or kilowatt-hours, delivered, in a circuit upon which a steady voltage is impressed. The watt-hours delivered in a given time may be computed by multiplying the ampere-hours by the voltage, since amperes $\times$ hours $\times$ volts $=$ amperes $\times$ volts $\times$ hours $=$ watts $\times$ hours. In commercial practice, more or less fluctuation in line voltage is unavoidable, so that inaccuracies may occur in the computation of watt-hours from ampere-hours. The ampere-hour is used directly, as a unit, in connection with the use of storage batteries, in other work involving electrolytic action, and in general when the measurement is one of quantity of current independent of the potential at which it is supplied.

The quantity of current may be measured by an **ampere-hour meter.** (See Chapter III.)

Inasmuch as the ampere-hour meter does not take care of possible fluctuations in line voltage, inaccuracies may occur in computing watt-hours from its registration. When, however, the variation of

voltage are not so great as to introduce errors exceeding the prescribed limits for the measurement of watt-hours directly, under the same conditions, meters registering ampere-hours may be employed instead of watt-hour meters. Ampere-hour meters may ordinarily be used without serious error where only small amounts of energy are involved. They can be used to advantage for special cases, where the potential of the circuit is not a factor in the desired measurement, such as electroplating or battery work, as described in Chapter XVI.

Electrical energy is distributed in the form of continuous (commonly called direct) current, and of single-phase, or polyphase, alternating current. Continuous current, and single-phase alternating current are distrib-

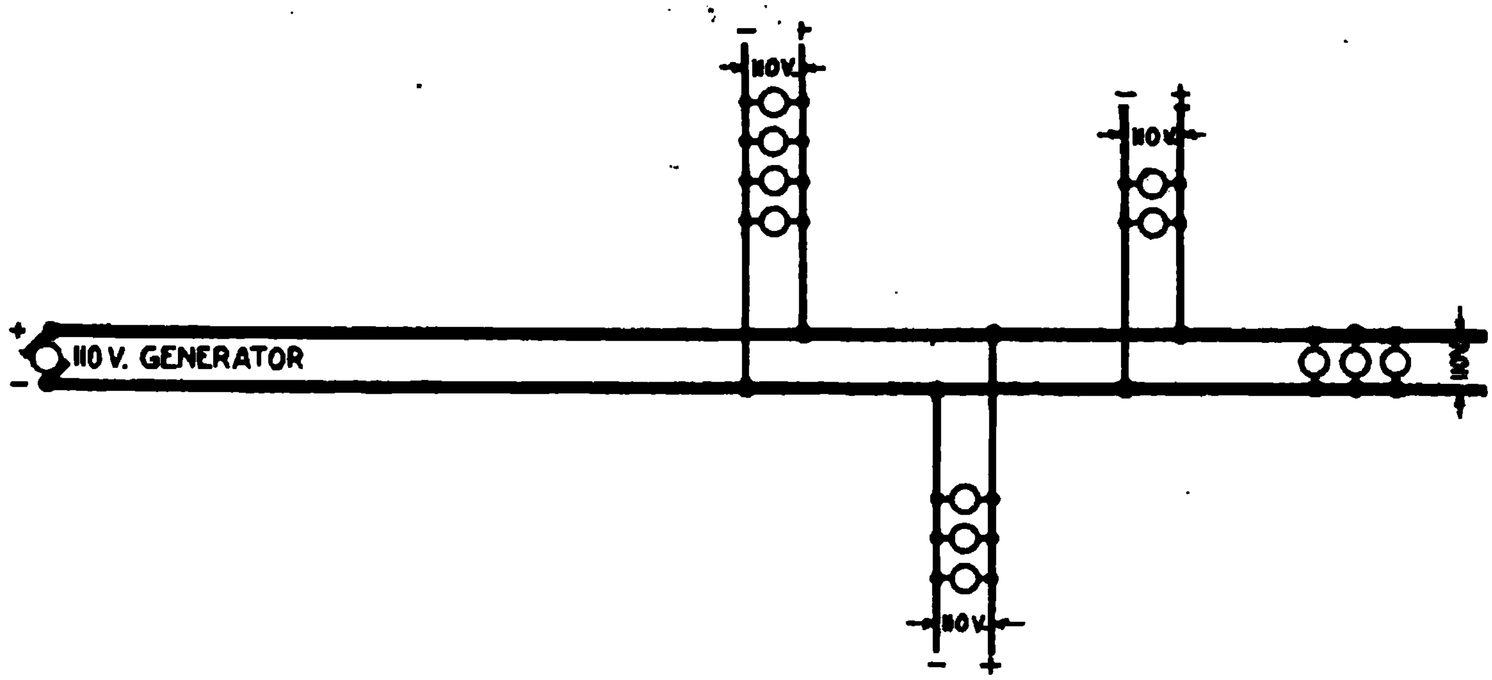


FIG. 107.—Two-wire System of Distribution.

uted on the consumer's premises, either in a two-wire, or a three-wire, system (Figs. 107 and 108).

A three-wire system has a middle or neutral wire intermediate in potential between the two outside wires (Fig. 108). Its advantage consists in the saving effected in wire, and the greater flexibility of the system, in that, from it can be obtained current at two voltages, as for instance, 110 volts for lighting and 220 volts for power.

A three-wire system is balanced when the currents in the outer wires are equal, and the potentials between the outer wires and the neutral wire are equal.

The power expended in a continuous current circuit is equal to the product of the values of the current flowing in the circuit and the potential between the terminals of the circuit, and is expressed by the formula:

$$P = EI.$$

In which P is the power in watts, E is the potential of the circuit in volts and I (formerly symbolized by C) is the intensity of current in the line in amperes.

The value of an alternating current is ordinarily understood to be equivalent to the number of amperes of continuous current which would produce the same effect such as the same amount of heat in an incandescent lamp filament. This is called the effective value, and can be shown to be equal to the number of amperes obtained by computing the square root of the average of all the values squared (i. e., the square

FIG. 108—Three-wire System of Distribution.

root of the mean square of all the values) through which the current passes in one cycle. It is sometimes called the "root mean square" value. (See Chapter II.)

The power expended in an alternating current circuit at any given instant in the cycle is equal to the product of the voltage and current at that instant.

When the current and voltage reverse at the same instant, this value is always positive, and if their wave forms are alike, the power expended is a maximum and is equal to the product of the effective values of voltage and current, as expressed in the formula for continuous current, in which case the current is said to be in phase with the voltage, or vice versa. When the term "power expended in an

alternating current circuit" is used, the average value during a cycle is ordinarily meant.

Circuits containing certain types of apparatus, such as transformers and induction motors, are known as reactive circuits, and have the property of storing up a part of the energy supplied to the circuit during a part of each cycle, and restoring this energy to the source during the remainder of the cycle. (See Chapter II.) This causes the reversal of current to take place at an earlier, or later, instant than the reversal of voltage, the current then being known as a leading, or lagging current. During the time when energy is being delivered, to the circuit, the product of current and voltage is positive; that is, the current and the voltage have the same sign. When either voltage, or current, is reversed with respect to the other, so that this product is negative, energy is being returned by the circuit to the source, and is then reckoned as negative. The net value of the energy delivered to the circuit per cycle is equal to the difference between the positive and negative values of energy in the two periods above referred to. The average value of the power for a given value of voltage and current is usually less than the product of the voltage and current (the volt-amperes) and may have any value between the value of the volt-amperes and zero. (Chapter III, Figs. 93, 94 and 95.)

The ratio between the power in watts expended in the circuit and the product of effective values of voltage and current (volt-amperes) is the power-factor of the circuit. The power-factor of a circuit is never greater than unity. (See Chapter II.)

When the wave-forms of the voltage and current are not the same, the power-factor of the circuit will be less than unity, even when the voltage and current reverse at the same instant, due to the fact that, in general, the voltage will be large when the current is small, and vice versa, thus diminishing the average product.

The phase difference, or phase angle, between a sine voltage and a sine current is defined as the number of electrical degrees between the beginning of the cycle of voltage and the beginning of the cycle of current. (See Chapter II.)

The power-factor of a circuit containing a sine voltage and a sine current is equal to the cosine of the phase angle between the voltage and current.

For reactive alternating current circuits, the right-hand member of the power equation given for continuous current circuits must be multiplied by the power factor of the circuit, which is usually expressed as the cosine of the phase angle ϕ, which angle equals the

number of degrees that the pressure is in advance of, or behind, the current.

The formula thus becomes:

$$P = EI \text{ Cos } \phi.$$

The energy delivered in a two-wire continuous current, or single-phase alternating current circuit is measured by a watt-hour meter,

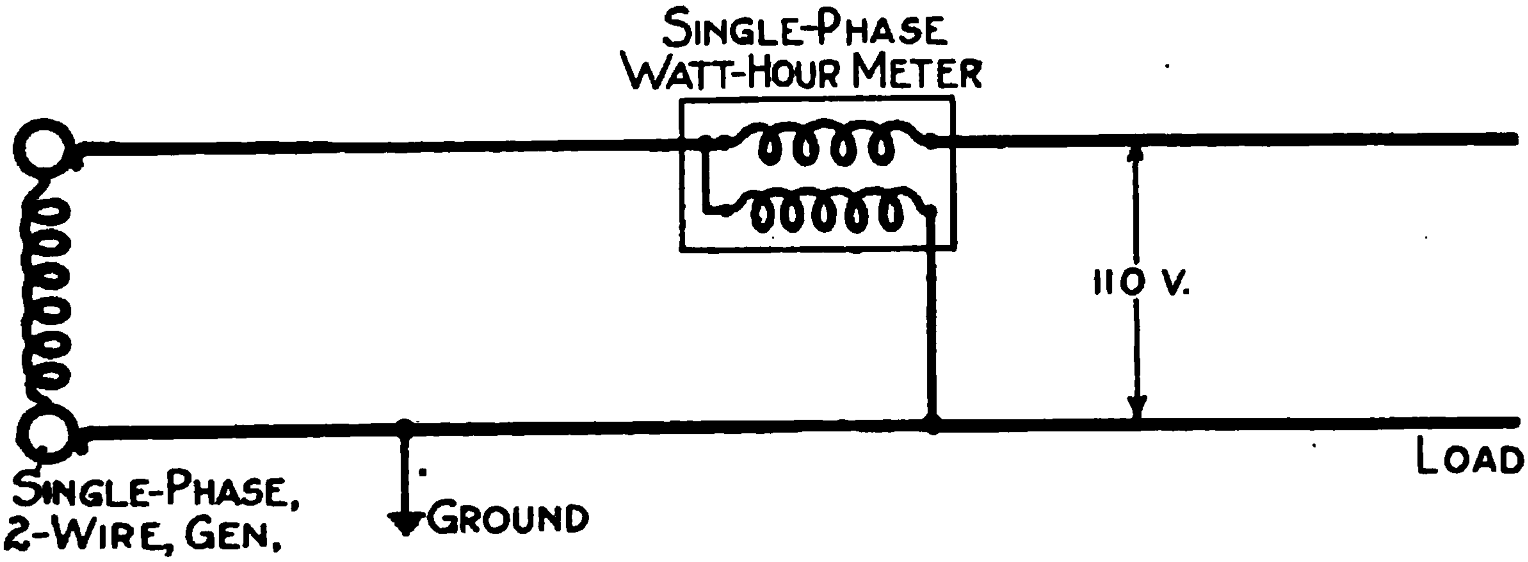


FIG 109.—Measurement of Energy Delivered in a Two-wire Circuit with Watt-hour Connected in Ungrounded Side.

or ampere-hour meter, having its current coils in the ungrounded side of the circuit, and, if a watt-hour meter is used, the potential coil connected across the circuit (Fig. 109). If neither side of the circuit is grounded, both sides may pass through the current coils of the

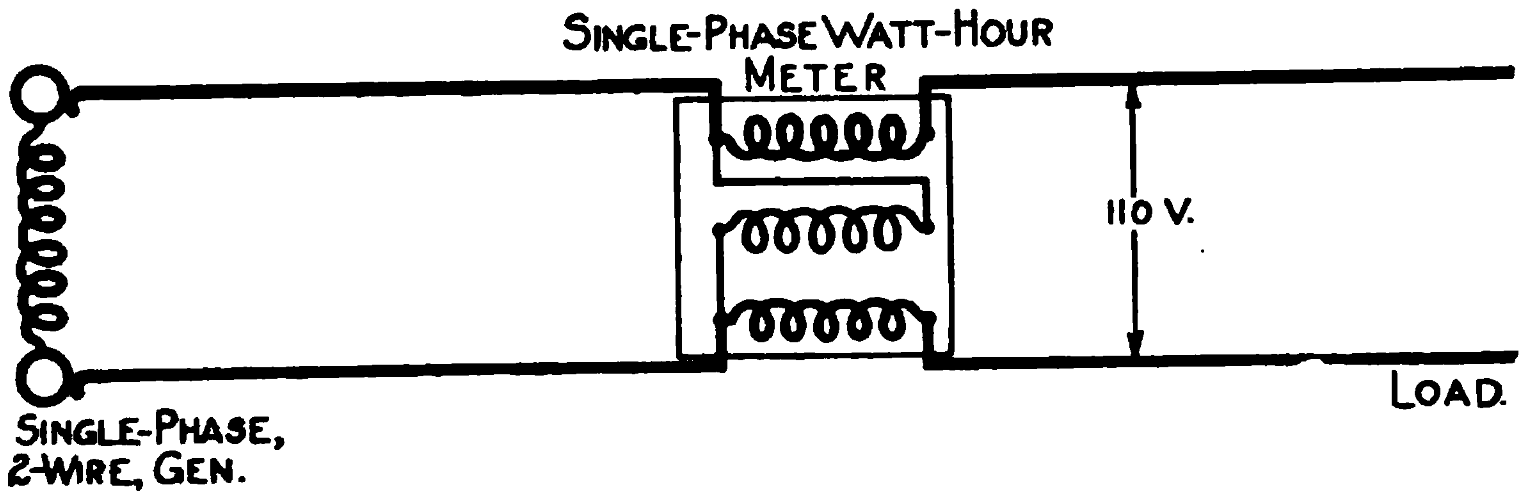


FIG. 110.—Measurement of Energy Delivered in a Two-wire Circuit with Watt-hour Meter having Two Separate Current Coils.

meter, if they are divided into two separate coils, as the current is the same in both sides (Fig. 110).

In the case of continuous current circuits carrying large currents, two, or more, meters may be used in parallel instead of one meter

capable of carrying the total current, or by means of a low resistance shunt, a definite proportion of the current only, may be passed through the meter (Fig. 111).

In the case of alternating currrent circuits carrying large currents, it is better practice to use current transformers (Fig. 112).

The energy delivered in a three-wire continuous current, or single-

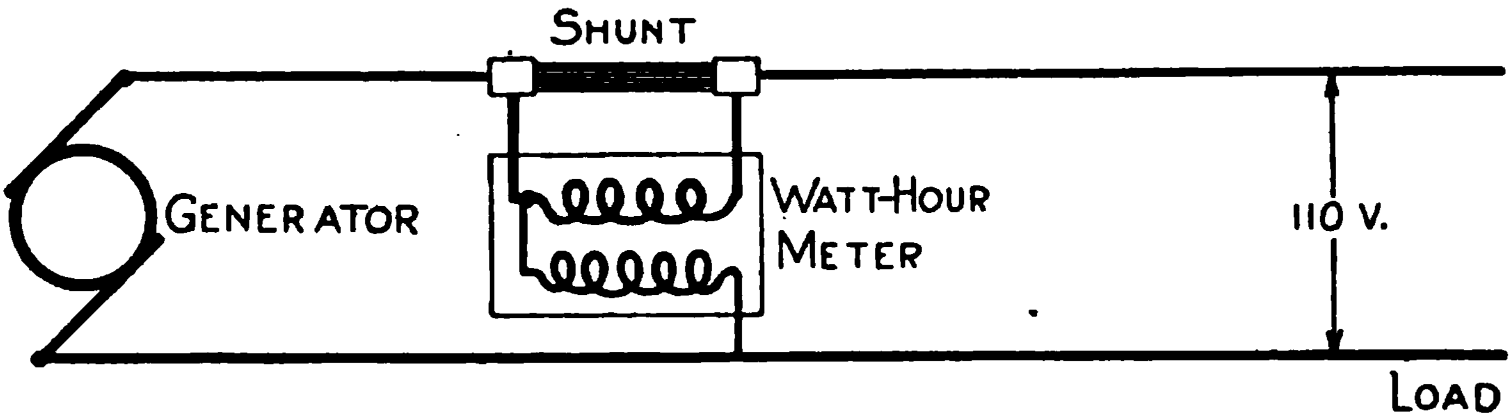


FIG. 111.—Measurement of Energy Delivered in a Two-wire Continuous Current Circuit with Shunted Type Watt-hour Meter.

phase alternating current circuit is the total of the amounts of energy in the two sides of the circuit considered as independent two-wire circuits and may be measured by two watt-hour meters with the current coils of one in one of the outer wires, and the current coils of the other in the other outer wire, and with the potential circuits connected from the lines in which the current coils are

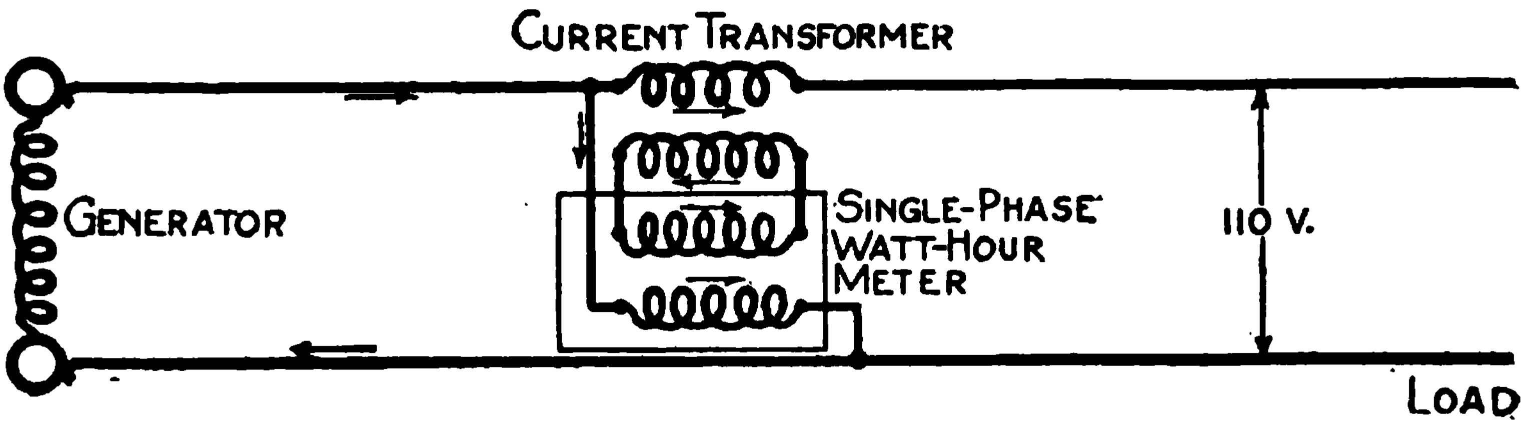


FIG. 112.—Measurement of Energy Delivered in a Two-wire Alternating Current Circuit with Current Transformer and Watt-hour Meter.

inserted to the neutral wire in both cases. The total energy is the sum of the two readings. As the potentials of the two sides of a three-wire circuit are practically equal, the two current coils may be put in one "three-wire" meter acting on a single moving element. The potential circuit should then be connected from one outer wire to the neutral wire. The accuracy of this meter is dependent on the potentials on the two sides of the system being balanced. Some of

the meters are so designed that the measurement is obtained by connecting the potential circuit between the outer wires. This meter is accurate only when either the potentials, or the currents, in the two sides of the system are balanced. The measurement of the unbalanced energy

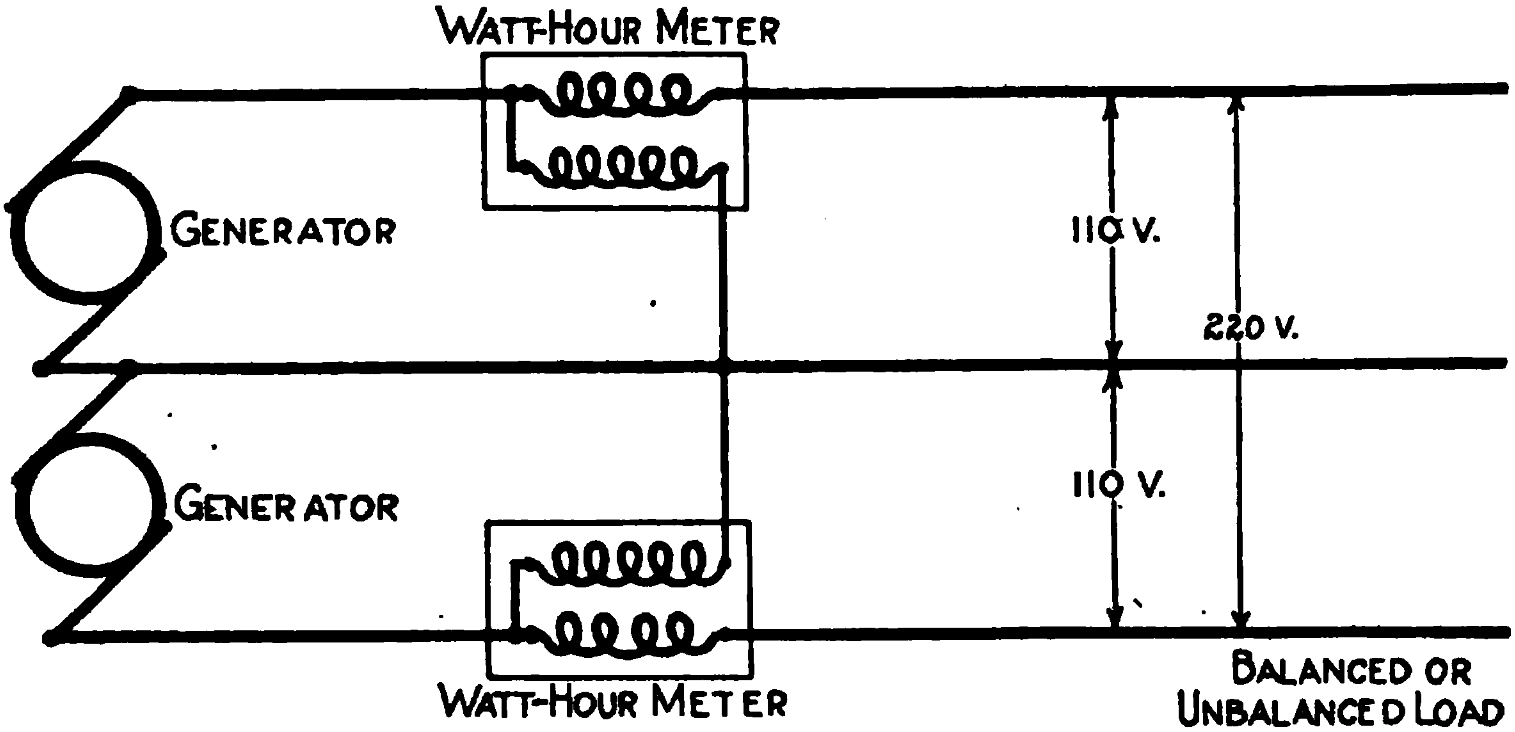


Fig. 113.—Measurement of Energy Delivered in a Three-wire Circuit with Two Watt-hour Meters.

in one side is the only portion subject to error when the potentials are unbalanced (Figs. 113, 114 and 115).

A three-wire ungrounded circuit could be measured with two meters connected in circuit in any two of the wires with the poten-

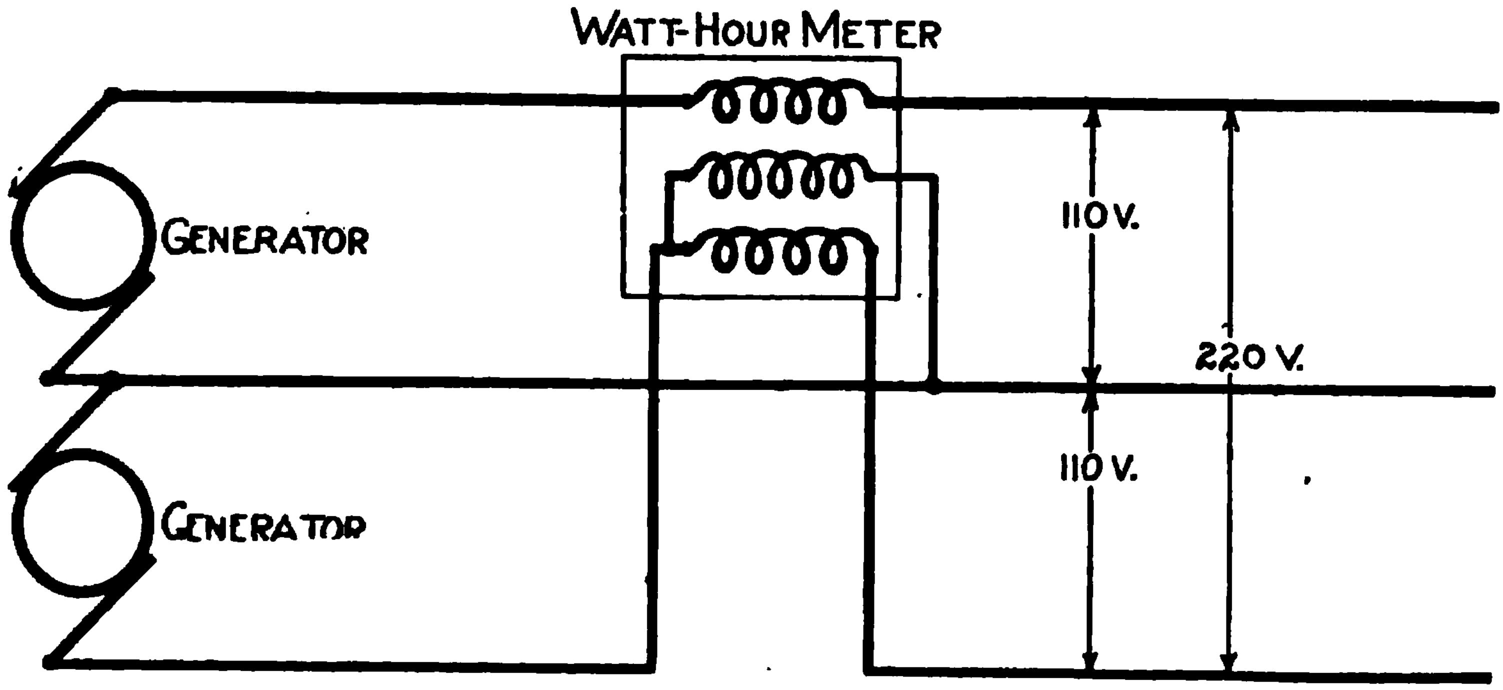


Fig. 114.—Measurement of Energy Delivered in a Three-wire Circuit with Three-wire Watt-hour Meter with Potential Element Connected to the Neutral.

tial of each connected to the third wire, provided the algebraic sum of the readings be taken; but unless the meters are connected in circuit in the two outer wires, the method is unnecessarily complicated.

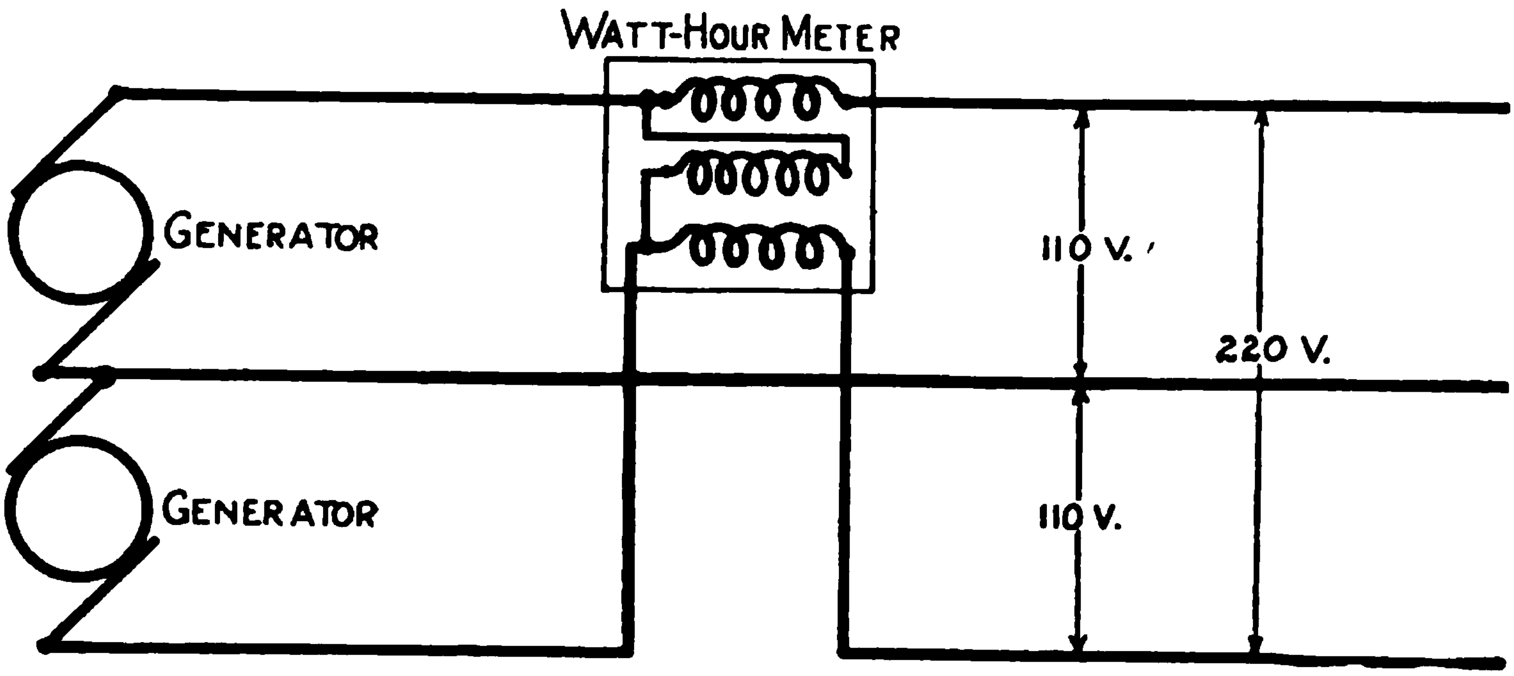


FIG. 115.—Measurement of Energy Delivered in a Three-wire Circuit with Three-wire Watt-hour Meter with Potential Element Connected between the Outer Wires.

The method depends on the principle that the exact measurement of electrical energy on any multi-wire system requires one less watt-

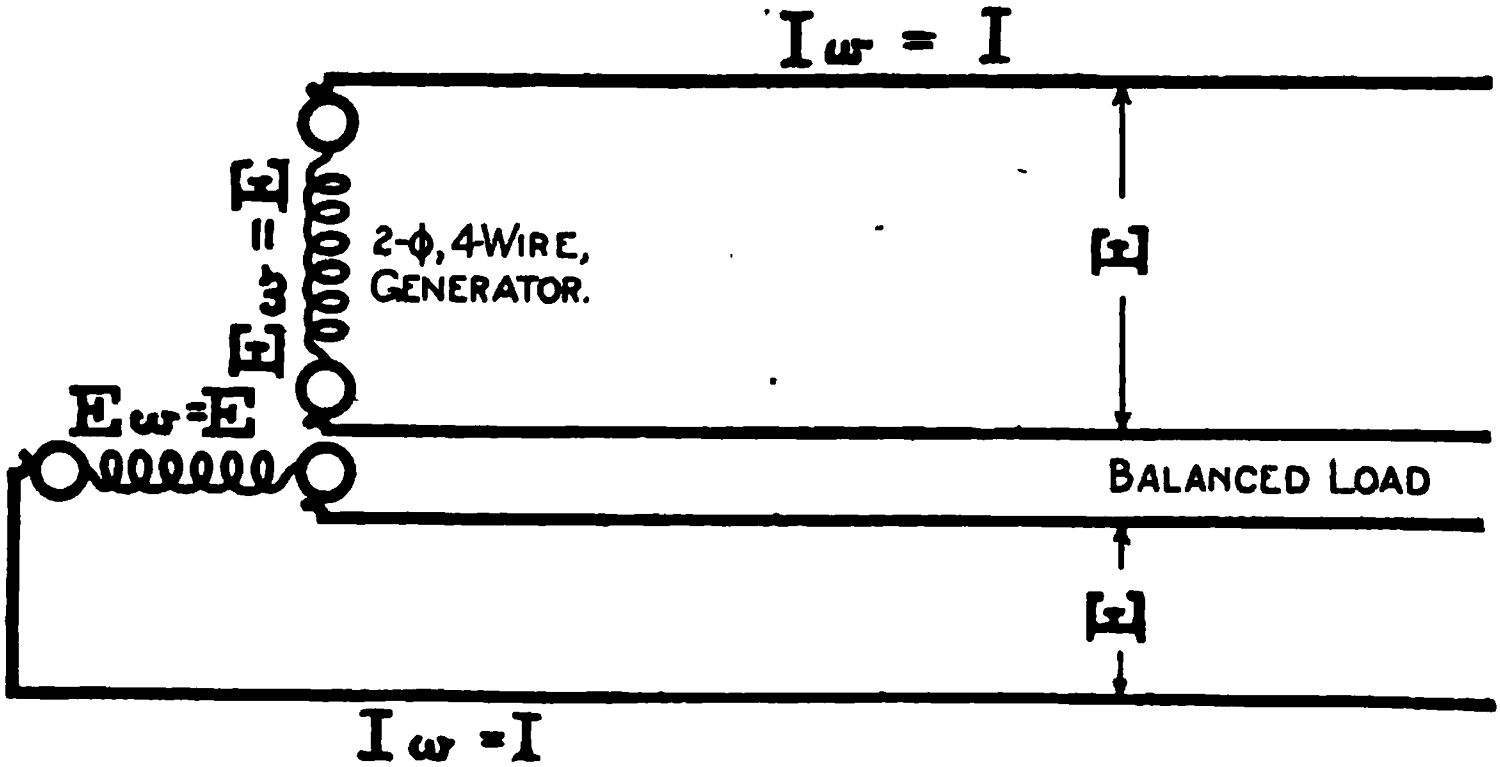


FIG. 116.—Two-phase, Four-wire Circuit with the Two Phases Separate.

hour meter element than there are wires in the system, and is demonstrated later in this chapter.

A very few systems employing five-wire distribution circuits were at one time installed, but the rarity of examples of this practice, and the identity of the principles of metering such systems with those just cited, justifies omission of further treatment in this work.

A polyphase circuit consists of two, or more, single alternating current circuits, in which the respective potentials are not in phase. The individual circuits making up the polyphase circuit are referred to as the various phases of the circuit, and the circuit is referred to as two-phase, or three-phase. according to the number of phases. Although special use is made of six-phase circuits, and other combinations, the meterman will scarcely ever be called upon to meter them as such, and, therefore, the discussions given here are confined to two-phase and three-phase circuits. (See Chapter II for definitions and elucidations.)

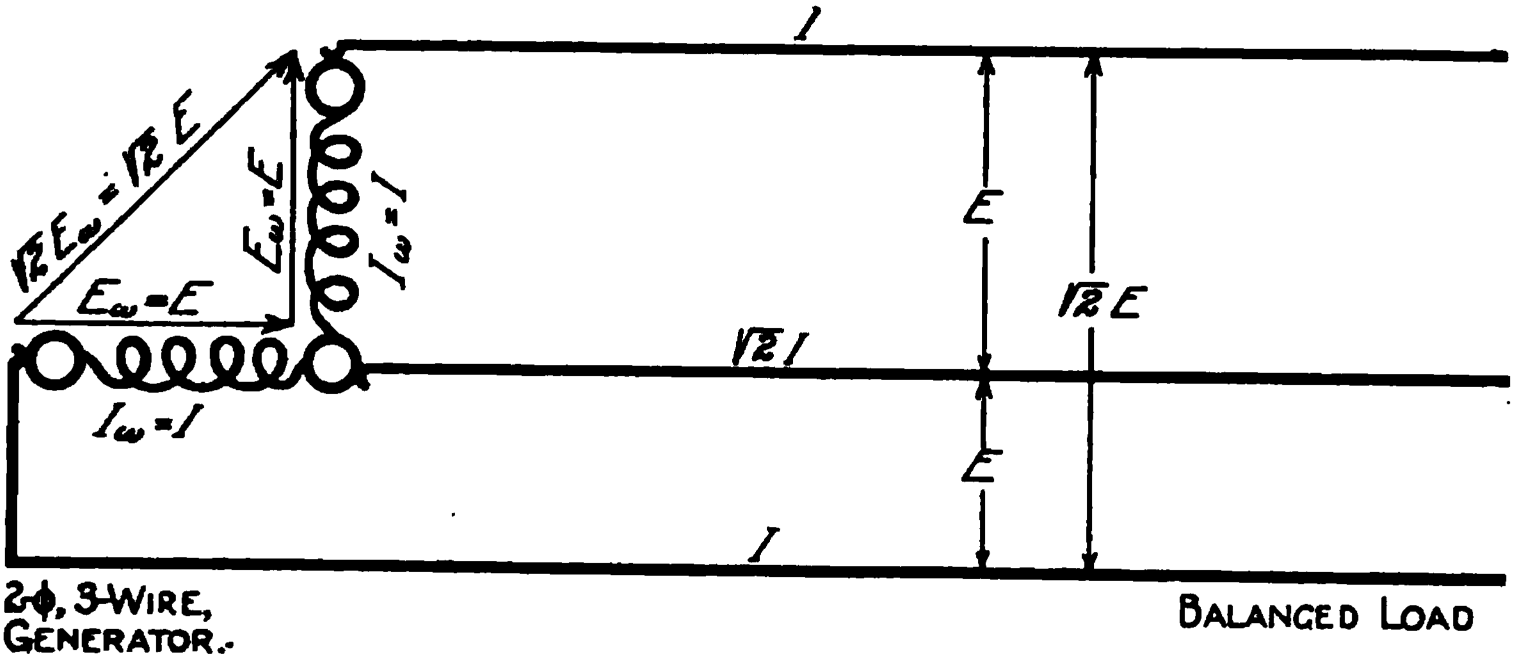


FIG. 117.—Two-phase, Three-wire Circuit with Common Return Wire.

A balanced load is said to exist in a polyphase circuit when all the receiving circuits have equal voltage, current and power-factor.

In **a two-phase circuit,** the potentials differ in phase by 90 electrical degrees. This was formerly called a quarter-phase circuit on account of the quarter rotation, or 90 degree relation between its phases.

The following **forms of two-phase circuits** are in use:

(a) **The two-phase, four-wire circuit,** in which the two **phases** are entirely **separate** and independent (Fig. 116).

(b) **The two-phase, three-wire circuit,** in which the two phases have a common return wire (Fig. 117).

(c) **The two-phase, four-wire circuit,** in which the two **phases** are

interconnected at the middle points of the phase windings, either in star or mesh fashion (Fig. 118).

The **electrical power in a two-phase circuit** is the sum of the amounts of power in each of the two phases, and, in a balanced circuit, may be expressed by the formula,

$$P = 2\,EI\,\mathrm{Cos}\,\phi,$$

in which P equals the toal power in watts, E the electromotive force in volts across each phase, and I the intensity of current in amperes in each phase.

In a two-phase three-wire circuit, the current in the common wire is equal to the vector sum of the currents in each phase. In a balanced

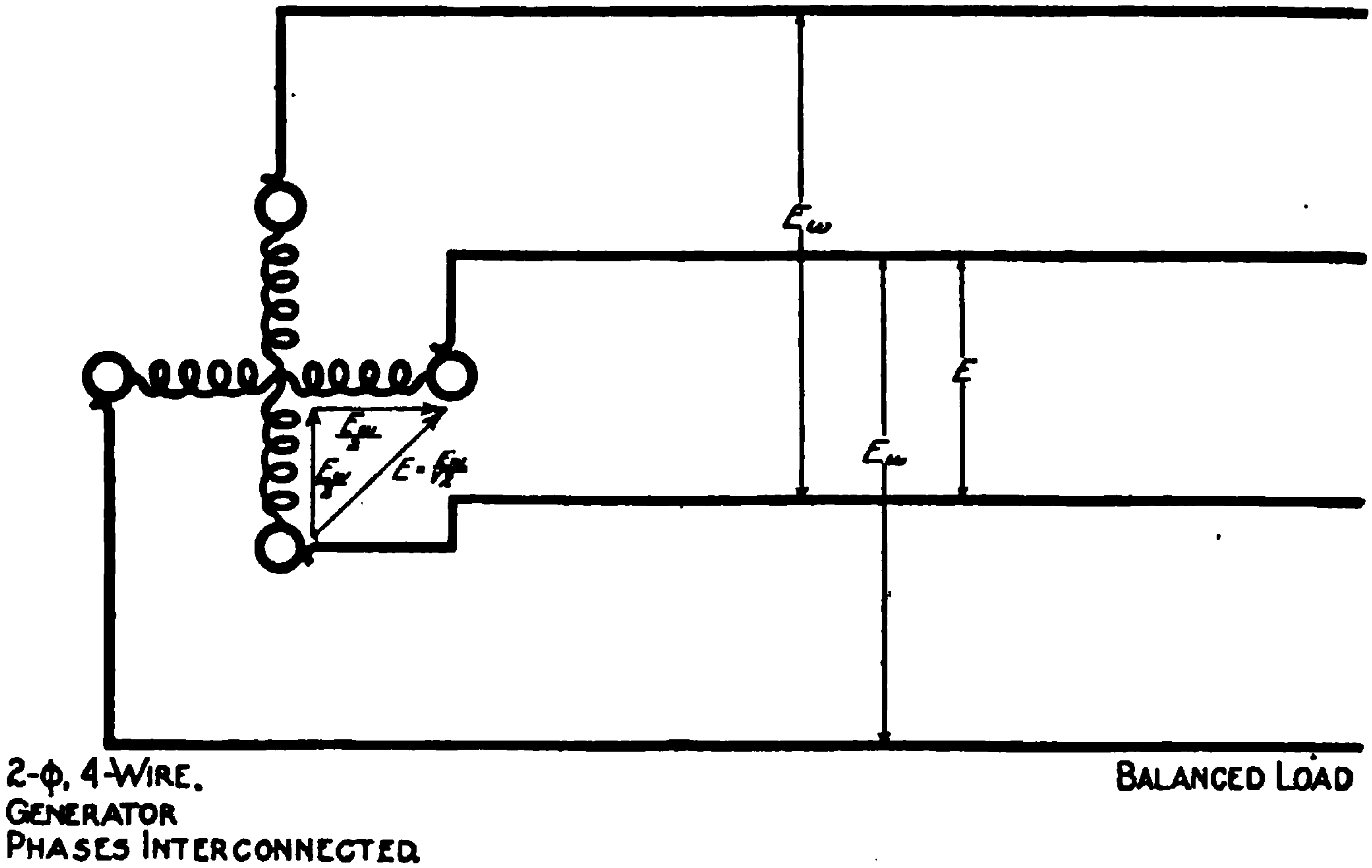


Fig. 118.—Two-phase, Four-wire Interconnected Circuit.

circuit the currents differ in phase by 90 degrees and the current in the common wire will consequently be $\sqrt{2}$, or 1.41, times as great as in the other wires, and midway between them in phase. The potential between the two-phase wires will be the vector sum of the two potentials which differ in phase by 90 degrees, and consequently will be $\sqrt{2}$ times the potential of one phase and midway between them in phase (Fig. 117).

In a two-phase, four-wire, interconnected circuit the potential between different phase wires will be the vector sum of half the potentials of the phases, or $\frac{E}{\sqrt{2}}$. (Fig. 118 and Chapter II.)

The energy expended in a two-phase circuit is measured by means of two watt-hour meters, one being connected in each phase, the method being correct for all values of unbalanced load and power-

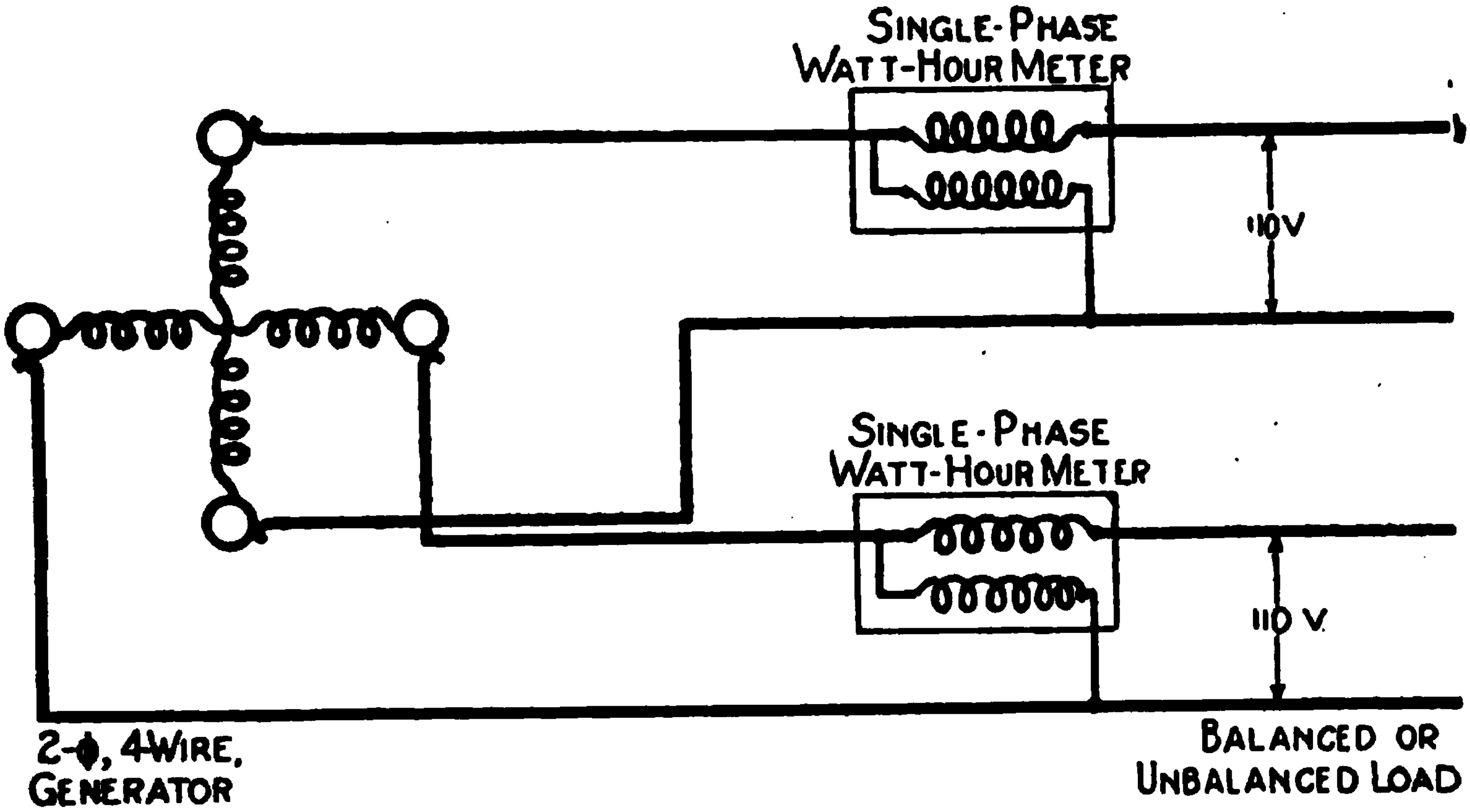


FIG. 119.—**Measurement of Energy Delivered in a Two-phase Circuit with Two Watt-hour Meters.**

factor, provided the load is connected across the respective phases. If the circuit is perfectly balanced the energy expended in each phase is the same and twice the reading of one watt-hour meter will

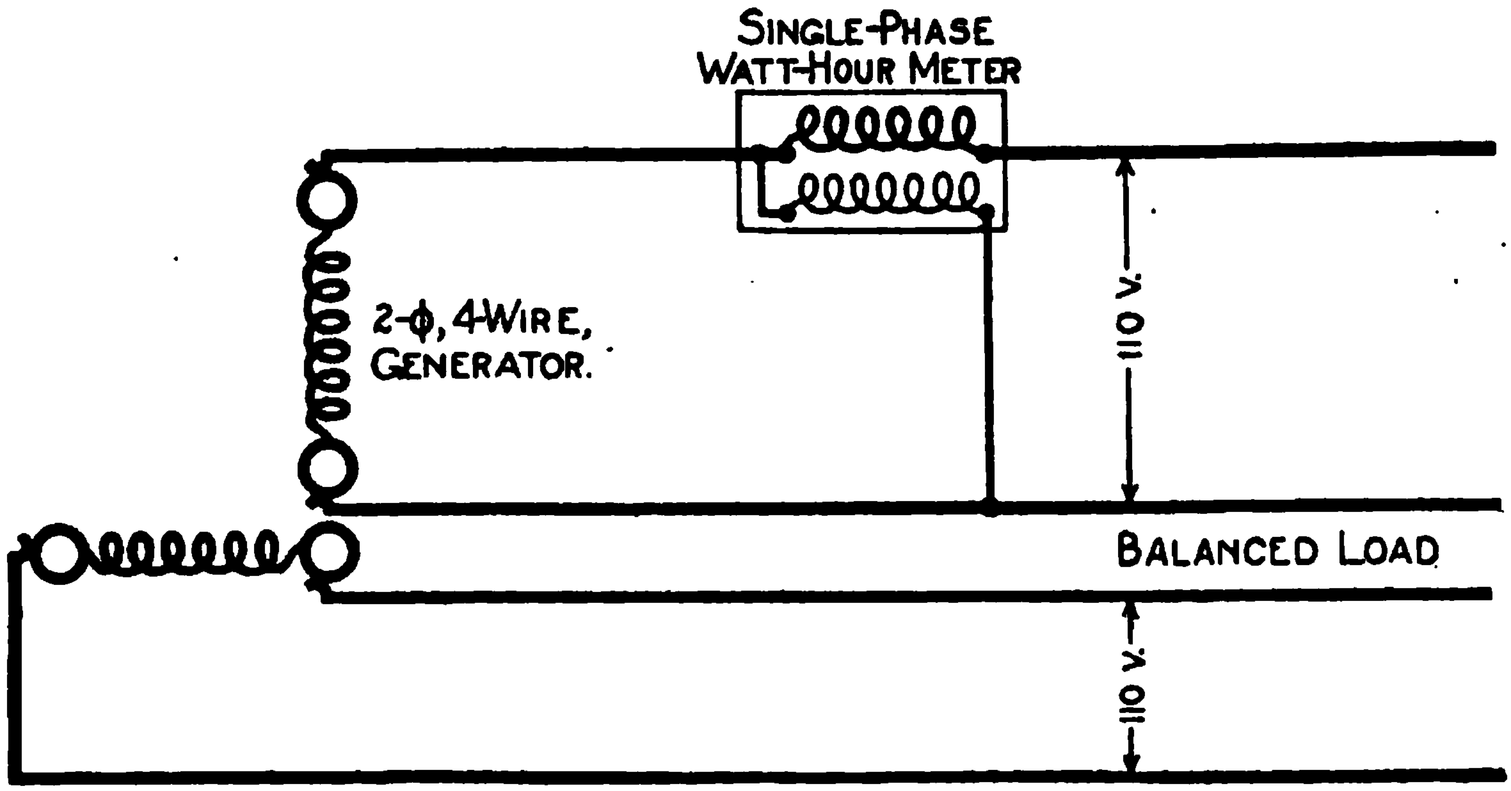


FIG. 120.—**Measurement of Energy Delivered in a Two-phase Circuit with One Watt-hour Meter, for Balanced Load Only.**

give the total energy, but this is a condition that cannot be obtained in commercial practice (Figs. 119 and 120).

Two-phase watt-hour meters are made, consisting of two separate, complete meter elements in one case, but with the moving part of

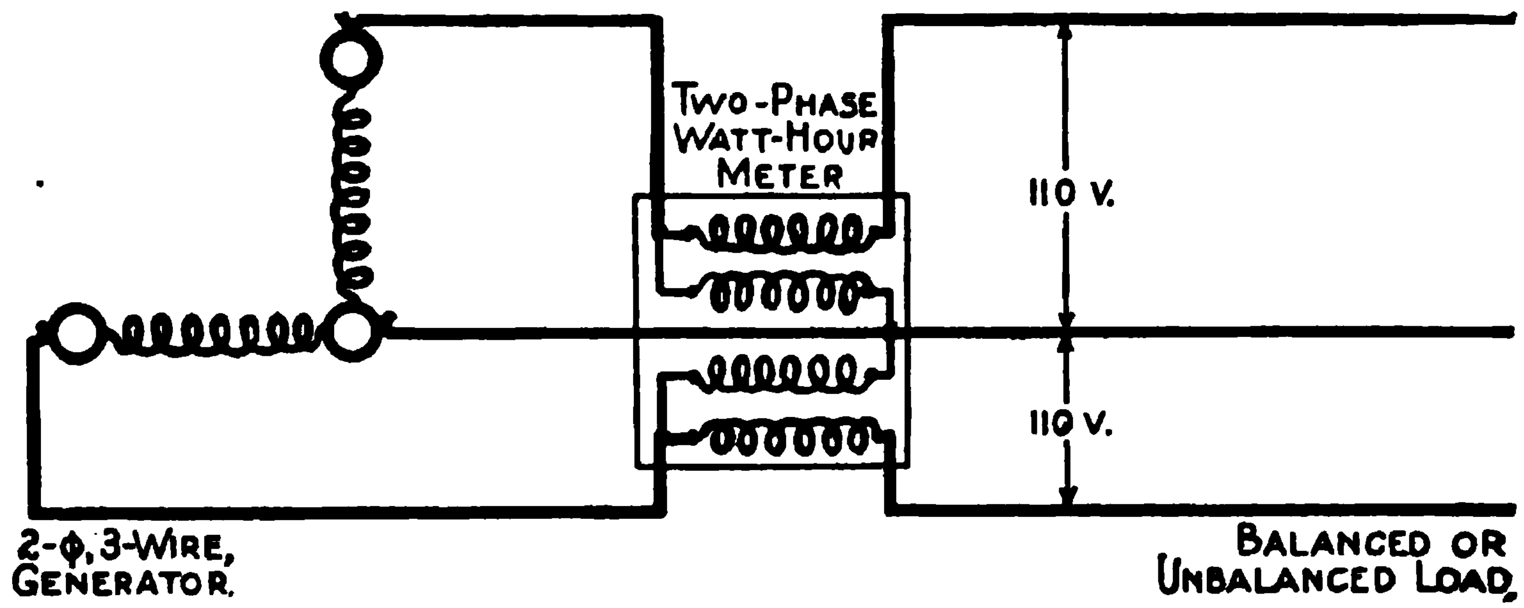


FIG. 121.—Measurement of Energy Delivered in a Two-phase Circuit with One Two-phase Watt-hour Meter.

each element mounted on the same shaft, so that the total energy is recorded on a single register (Fig. 121).

In a **three-phase circuit**, the difference in phase between the potentials of any two of the circuits is 120 electrical degrees, the same

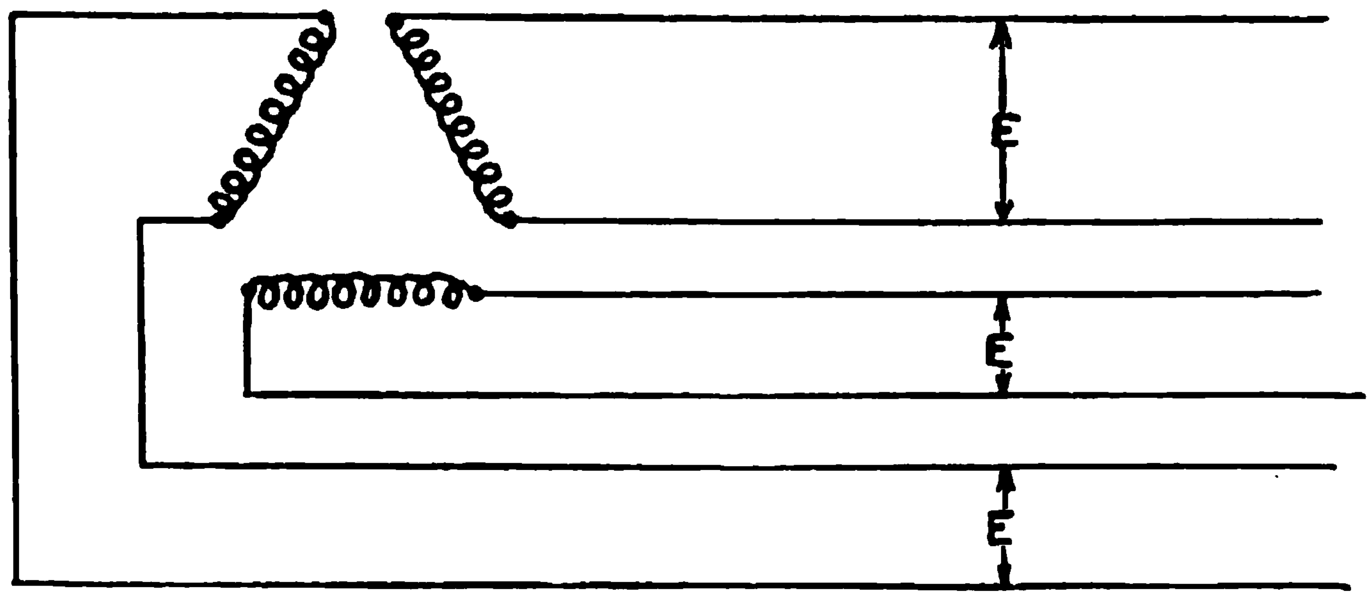


FIG. 122.—Three-phase, Six-wire Circuit with the Three Phases Separate.

relation applying to the currents, when the circuit is balanced. The three-phase circuit might have six line wires, no connections existing between any two of the phases (Fig. 122). It is the practice, however, to reduce the number of line wires to four, or three, by combining them.

Three-phase circuits may be combined at both the generating and receiving ends by means of either **star, or delta,** connections. (See Figs. 123, 124 and 125).

The potential of a three-phase circuit is generally considered as

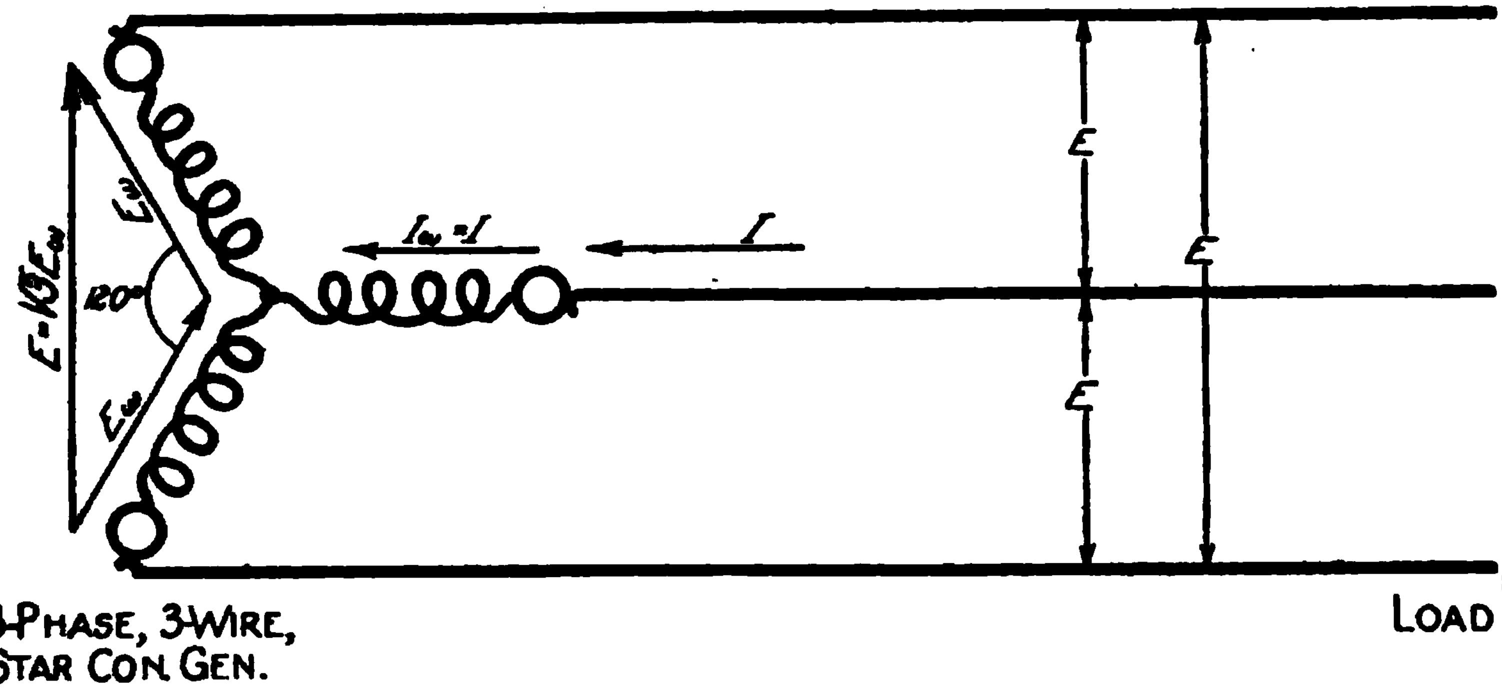


FIG. 123.—Three-phase, Three-wire Circuit, Star Connected.

the voltage between any two of the three-phase wires. In a star-connected generator, it is evident that these potentials are not the same as the potentials generated in the phase windings, but are equal to the vector sum of the potentials of the two phase windings across

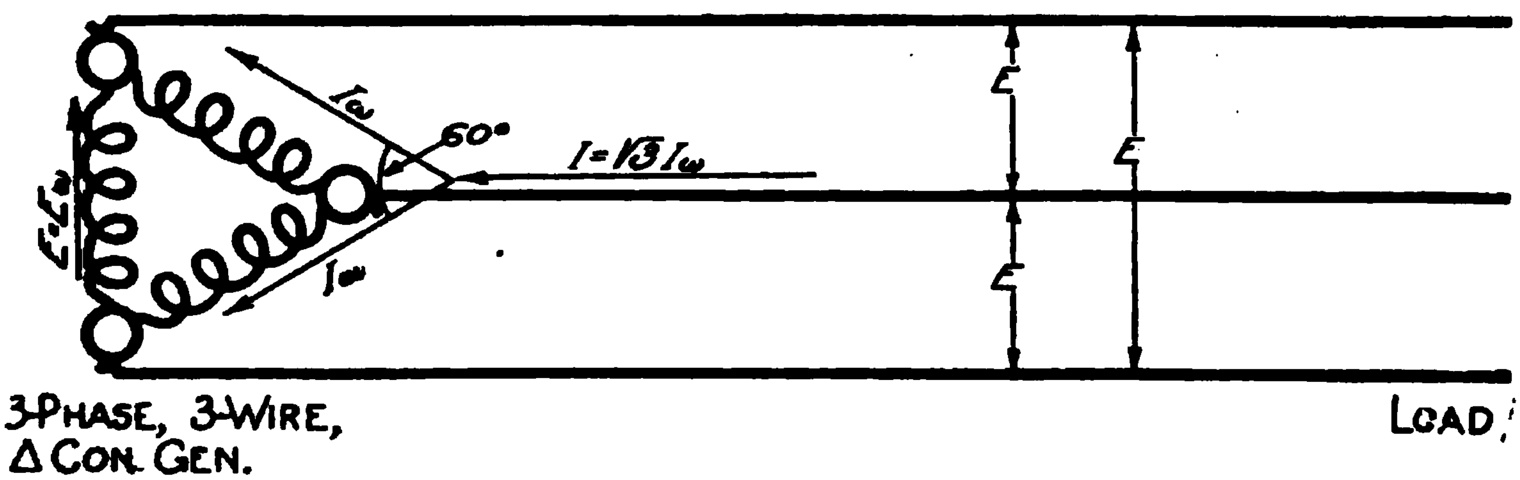


FIG. 124.—Three-phase, Three-wire Circuit, Delta Connected.

which the delta connections are tapped. If the system is balanced, then the potential between any two of the phases is equal to the potential in the phase winding times $\sqrt{3}$ (Fig. 123 and Chapter II); or, in terms of the potential of the circuit, the potential in the phase

winding, *Ew*, equals $\frac{E}{\sqrt{3}}$. The current in each phase winding, *Iw*, is, in a star-connected generator, equal to the line currents, *I*.

The power, in watts, in one phase winding equals $\frac{E}{\sqrt{3}}$ *Iw* Cos ϕ or, substituting *I* for *Iw*, equals

$$\frac{EI \text{ Cos } \phi}{\sqrt{3}}$$

where E is the potential of the circuit, between any two phase wires; I is the current in any one phase wire, equal to *Iw*, the current in one

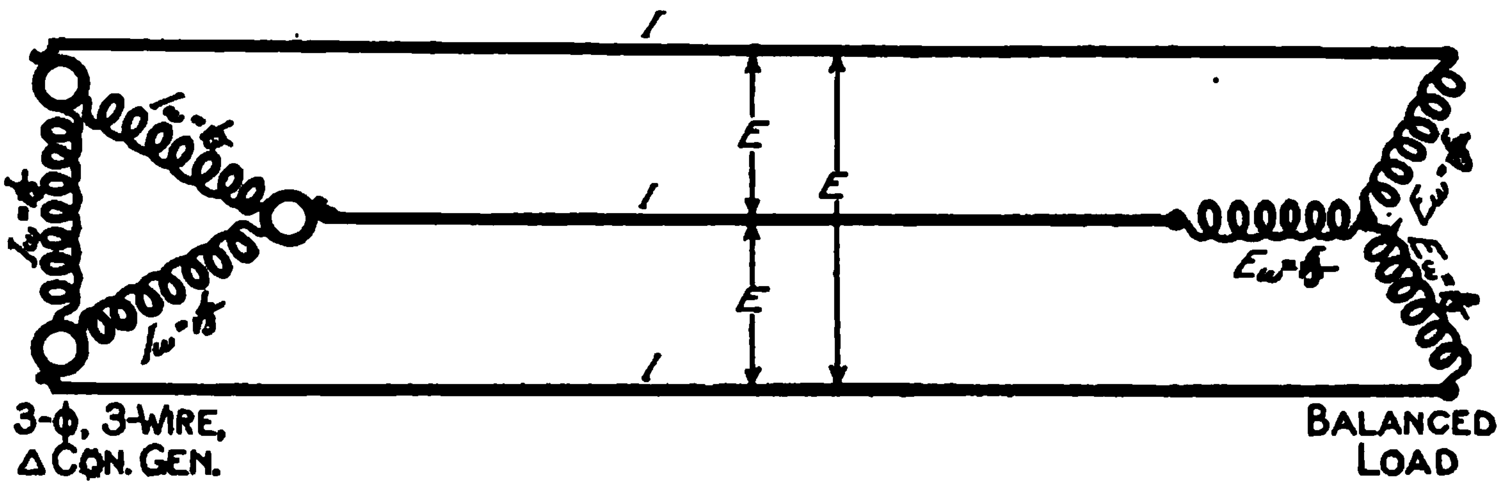


FIG. 125.—Three-phase, Three-wire Circuit Connected Delta at Generating End and Star at Receiving End.

phase winding, and Cos ϕ is the power factor of the phase under consideration.

The power in a balanced three-phase, star-connected circuit is equal to three times the power in one phase winding, or

$$P = 3 \times \frac{EI \text{ Cos } \phi}{\sqrt{3}} = \sqrt{3}\, EI \text{ Cos } \phi$$

in which I is the current in any one phase wire, and E the potential between any two phase wires, and Cos ϕ is the power-factor of any one phase, as the assumption of a balanced polyphase circuit makes all similar characteristics of the different phases equal.

In a delta-connected generator, the current in the phase wire, or line wire, equals the vector sum of the currents in the two adjacent phase windings, and the current in one phase winding, *Iw*, equals $\frac{I}{\sqrt{3}}$ (Fig. 124). The potential across each phase winding, *Ew*, is, in a delta-

The power, in watts, in each phase winding will therefore be $Ew \times \frac{I}{\sqrt{3}} \times \text{Cos}\ \phi$, or, substituting E for Ew, equals

$$\frac{EI\ \text{Cos}\ \phi}{\sqrt{3}}$$

where E is the potential between any two phase wires, equal to Ew, the potential across any one phase winding, I is the current in one-phase wire, and Cos ϕ is the power-factor of the phase under consideration.

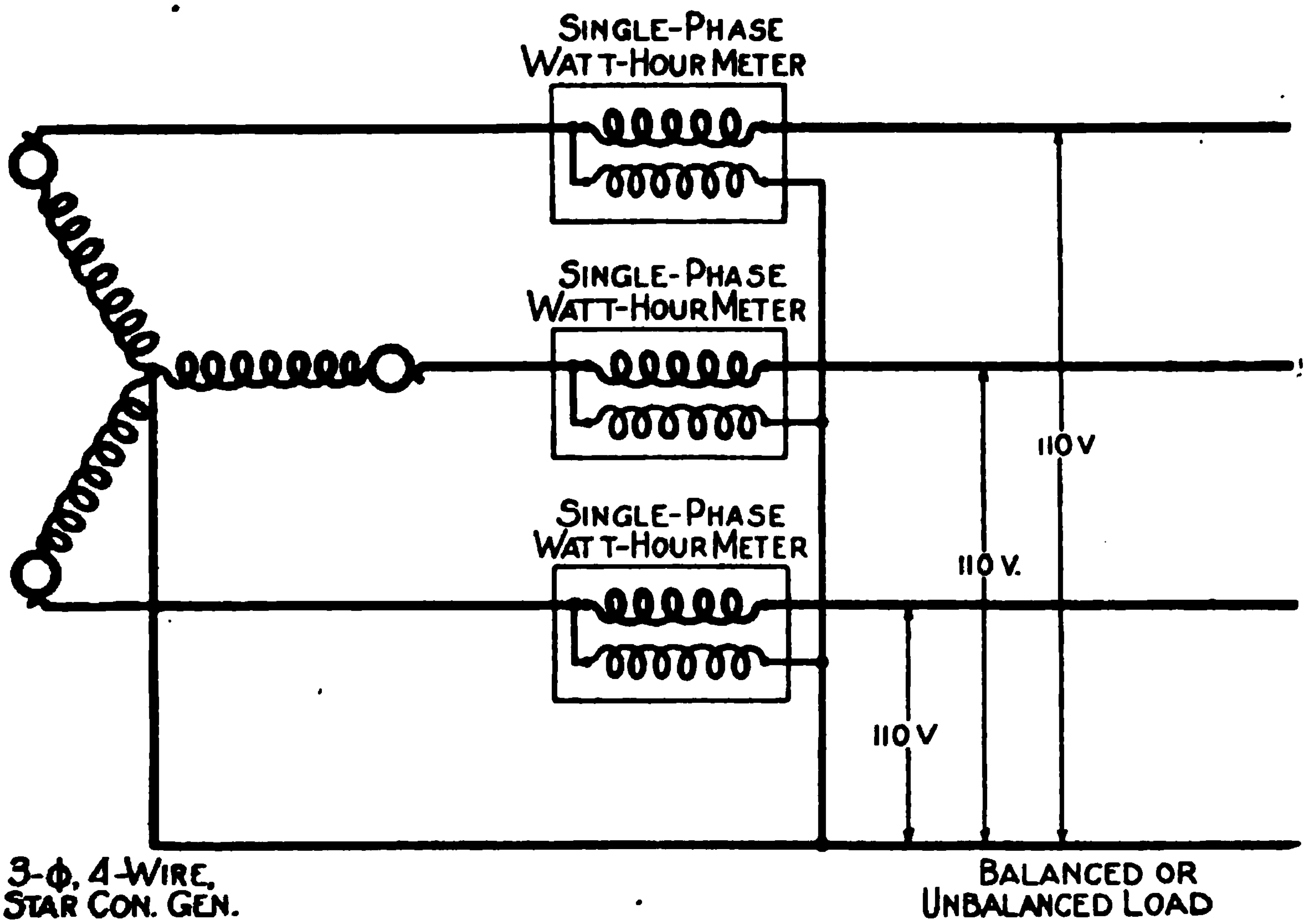


FIG. 126.—Measurement of Energy Delivered in a Three-phase Star Connected, Four-wire Circuit with Three Watt-hour Meters.

The total power in the three-phase, balanced, delta-connected circuit is three times this amount, which gives the same result as with a star-connected generator.

$$P = \sqrt{3}\ EI\ \text{Cos}\ \phi.$$

The following methods are suitable for **measurement of energy delivered in three-phase circuits.** The kind of system and the

nature of the connected loads must be considered in determining which method should be used.

Three-meter method: If the energy delivered by a generator or absorbed by a motor, or other device which is connected in star fashion, is to be measured, three watt-hour meters may be used with the current element of each in different phase wires and the potential circuits connected to the common, or neutral, point, provided this is accessible (Fig. 126).

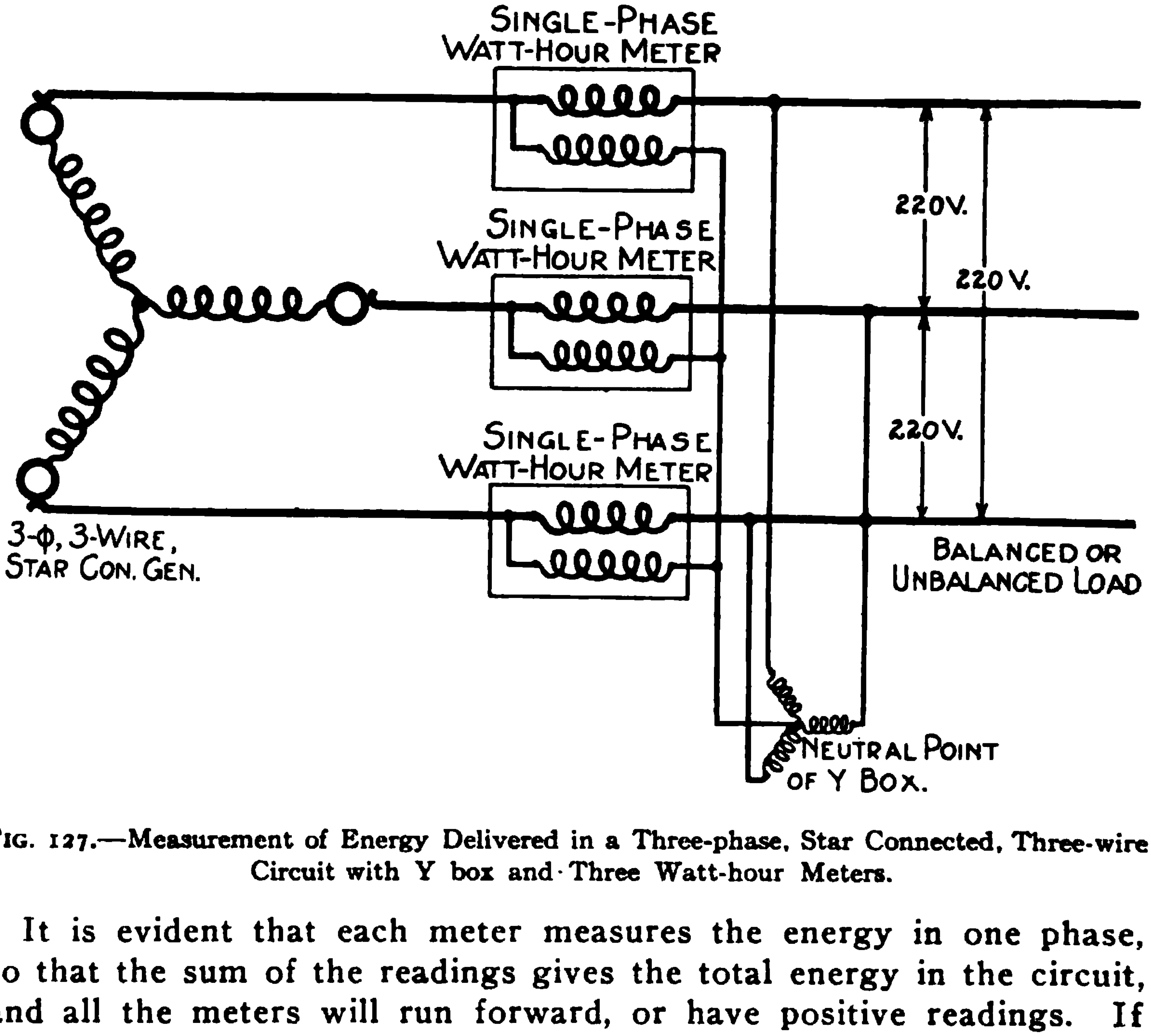


FIG. 127.—Measurement of Energy Delivered in a Three-phase, Star Connected, Three-wire Circuit with Y box and Three Watt-hour Meters.

It is evident that each meter measures the energy in one phase, so that the sum of the readings gives the total energy in the circuit, and all the meters will run forward, or have positive readings. If the circuit is balanced, each watt-hour meter will measure one-third of the total energy, and hence be a check on the accuracy of the other two.

If the neutral point is not accessible, or the devices are connected in delta, this method may be used by the creation of an artificial neutral point, as shown in Fig. 127. For this purpose a Y box, consisting of three equal non-inductive resistances, should be connected together at one end, which will then become a neutral point.

and the other ends connected to the three phase wires. Care must be taken that the impedances of the watt-hour meter potential coils are so large compared with the three auxiliary resistances that connecting them in circuit does not disturb the pressure at the neutral point. This method is open to the objection that there will be an appreciable constant loss of power through the non-inductive resistances. If the impedances of the watt-hour meter potential coils are exactly equal, auxiliary resistances are unnecessary, and the measurement may be made by joining the free ends of the three potential

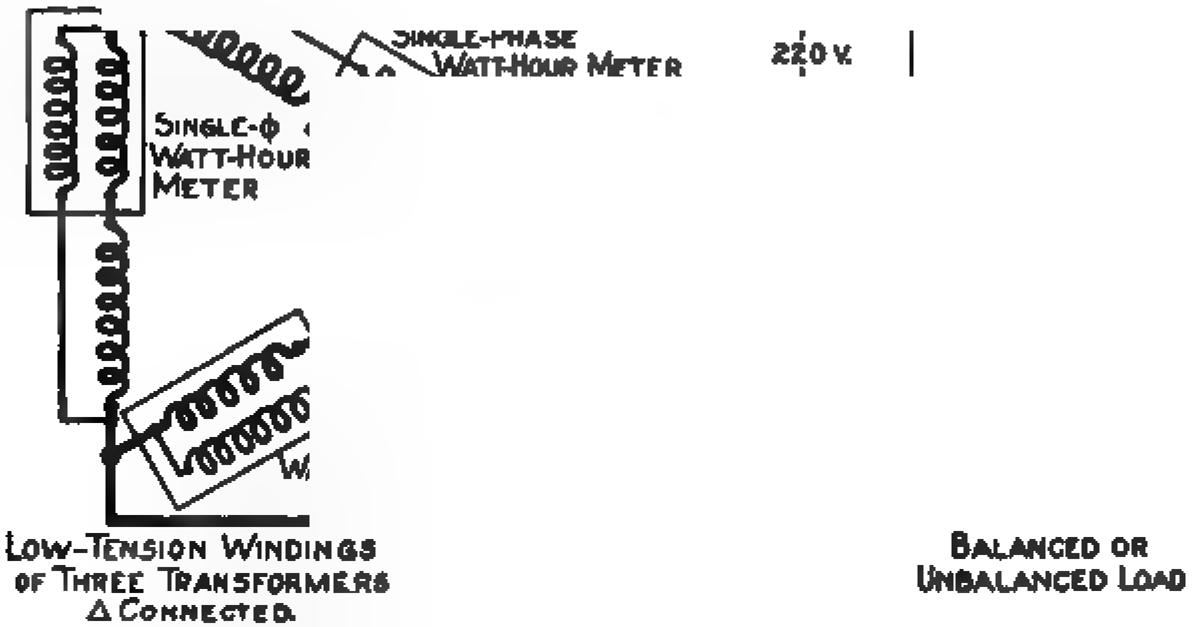


Fig. 128.—Measurement of Energy Delivered in a Three-phase, Delta Connected, Three-wire Circuit with Three Watt-hour Meters Inserted into the Coil Circuits.

coils. This neutral is sensitive to line disturbances and the effect of harmonics, and the potential to the neutral point obtained in this way may be increased to a value greater than $\frac{E}{\sqrt{3}}$, owing to the presence of higher harmonics (Chapter II). These higher harmonics do not affect the accuracy of the method, provided the meter is accurate at the higher potential and with the altered wave form, owing to the fact that the distorted form of the voltage curve proportionately decreases the power-factor.

If the devices are connected in delta, three watt-hour meters may also be used, provided they can be inserted directly into the coil circuits, or phase windings, of the device, as shown in Fig. 128.

The energy in the circuit is equal to the sum of the three watt-hour meter readings, and if the current is exactly balanced, each watt-hour meter will register one-third of the total energy. This method, however, is not usually commercially practical.

All of the three-meter methods are correct for all values of balanced, or unbalanced, load, and at all values of power-factor in the receiving circuit.

Two-meter method: The energy in a three-wire, three-phase circuit absorbed by either star, or delta, connected devices, may be measured by means of two watt-hour meters, one having its current coils connected in one of the phase wires and the other with its

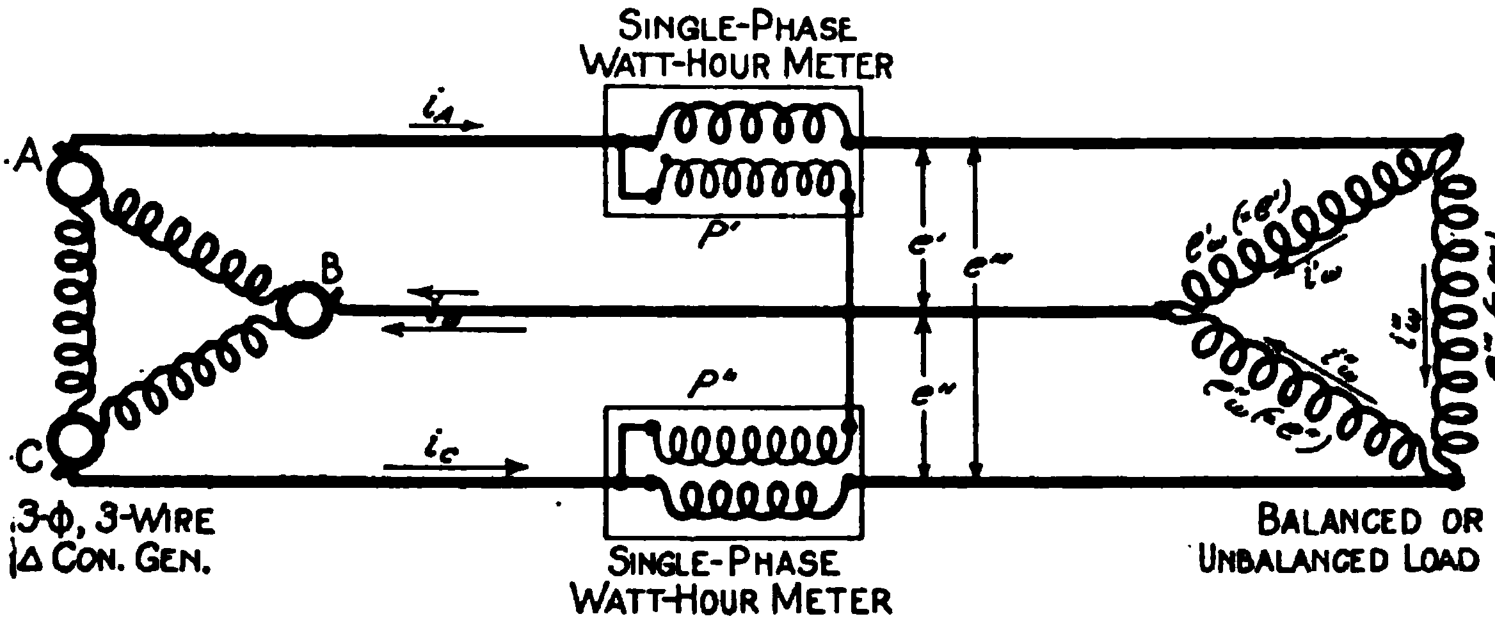


FIG. 129.—Measurement of Energy in a Three-phase Circuit with Two Watt-hour Meters.

current coils connected in another, and each having its potential circuit connected from the phase wire in which its current coils are connected to the third phase wire (Fig. 129). The algebraic sum of the readings of the two meters gives the energy in the circuit, with entire independence of the balance of the circuit, or current lag. When the current lag in the circuit is less than 60 degrees, or the power-factor is greater than .50, the arithmetical sum of the readings is equal to the energy in the circuit, but if the lag is greater than 60 degrees, or the power factor is less than .50, the torque due to the changed relation of the currents in the current and potential coils on one of the meters, causes it to move backward, or have a negative reading, and the arithmetical difference, or algebraic sum, of the readings gives the total energy.

The following simple statement to demonstrate the **validity of this method of measurement** is quoted from Mr. C. A. Adams (Electrical World, page 143, vol. xlix):

"In any n-wire system (continuous current or alternating current;

balanced or unbalanced) assume one wire as a common return for the other n-1 wires, considered as carrying the outgoing currents of n-1 separate circuits, and connect n-1 watt-hour meters as if to measure the energy in these n-1 separate circuits. Then the algebraic sum of the readings of these n-1 watt-hour meters will be the total energy passing in the system.

"That the statement in the preceding paragraph is entirely sufficient without further proof seems almost self-evident, but will be made more clear by the following illustrations:

"In any three-wire system, label the three wires A, B, C, as in Fig. 129. The current in B, counted backward toward the generator, is at each instant equal to the algebraic sum of the currents in A and B, counted outward from the generator, i. e., B may be looked upon as a common return for A and C.

"Imagine the B wire to be divided longitudinally into two parts, one the return for the current A and one the return for the current C; then it is obvious that the system is entirely equivalent to a two-phase, or two-circuit, system, one phase, or circuit, carrying the A current and the AB voltage, and the other the BC current and the BC voltage and that the two watt-hour meters measure the amounts of energy in these two phases, or circuits, independently of any question of the balance of the system. No assumption whatever is made as to the actual arrangements of the circuits beyond the watt-hour meters, the equivalence to the two-circuit arrangement being equally valid in all cases. In fact, any proof based upon the assumption of a particular arrangement of circuits does not ordinarily hold good for any other arrangement.

"One very practical advantage of the point of view here adopted is that the indicating wattmeters may be readily connected into the circuits without trial, in such a manner that the algebraic sum of their indications will be the total power of the system. If, when so connected, one of them gives a negative indication, it shows that its reading (when the connections to its potential coils, or to its current coil, are reversed) should be taken with a negative sign."

Another method of analyzing the **correctness of the two-meter method** of measuring the energy in a three-phase circuit is as follows:

With the meters connected as suggested above for three-phase measurement and the circuits imagined to be divided as suggested by Mr. Adams, it may be considered that the watt-hour meter which has its current coils connected in the A wire and its potential element connected between wires *A* and *B* will measure the energy sup-

plied by the phase winding AB. The watt-hour meter which has its current coils connected in the C wire and its potential element connected between wires C and B will measure the energy supplied by the phase winding CB.

In addition to the above, the two meters will measure in series the energy supplied between phase winding AC, as the potential coils of the meters are, as far as the AC potential is concerned, virtually connected in series across the A and C wires, dividing this voltage equally between themselves, and each, therefore, operating at one-half the total AC potential. The toal current generated by the AC phase winding passes through the current coils of each of the watt-hour meters, and, under the above conditions, therefore, each of the meters may be considered to be recording one-half the energy supplied by the AC phase winding, or the total current generated by the AC winding at one-half the AC voltage. Each meter may, therefore, be considered as registering one and one-half times the energy in any one of the phase windings, and the two meters, therefore, measure three times this energy, or the total in the three-phase circuit.

That **two watt-hour meters are sufficient for the complete measurements of the energy taken by any three-phase receiving unit,** the connections being as shown in Fig. 129, and the receiving circuit being balanced or unbalanced, and connected star or delta, is proved by Franklin and Williamson, on page 112 of their work on Alternating Currents.

"Let the positive direction in the mains A and B, and in the three receiving circuits, be chosen as indicated by the arrows in Fig. 129. These directions are chosen symmetrically with respect to the two watt-hour meters. Let the instantaneous currents in the receiving circuits be $i'w$, $i''w$ and $i'''w$, as shown.

"Let i_A be the instantaneous current in the main A, and let i_B be the instantaneous current in main B. Then

$$i_A = i'_w + i'''_w$$
$$i_B = i''_w - i'''_w$$

"The reading P' of the upper watt-hour meter is equal to the average value of the product of the current i_A, which flows through the current coil of the instrument into the electromotive force e', which acts upon the shunt circuit of the instrument. That is,

$$P' = \text{average } i_A e'.$$

Similarly

$$P'' = \text{average } i_B e''.$$

Substituting the above values of i_A and i_B in the expression for $P' + P''$, we have

$$P' + P'' = \text{average } e' \; i'_w + \text{average } e'' \; i''_w + \text{average } (e' - e'') \; i'''_w$$

But $e' - e'' = e'''$, so that

$$P' + P'' = \text{average } e' \; i'_w + \text{average } e'' \; i'' + \text{average } e''' \; i'''_w.$$

An algebraic demonstration of the accuracy of this method of measuring three-phase energy may be found on page 368 in "Polyphase Electric Currents," by Silvanus P. Thompson.

Three-phase watt-hour meters are generally made on the two-meter principle and consist of two separate complete meter elements

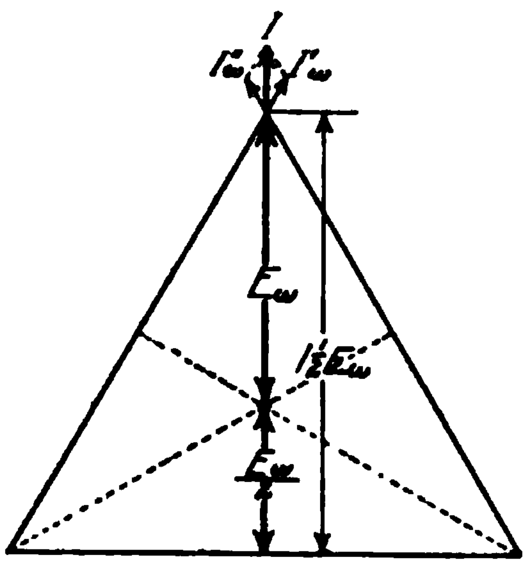


Fig. 130.—Diagram showing that Potential to Middle Point of Auto-transformer is 1½ times the Voltage to Neutral, and is in Phase with the Current *I*, and that, therefore, One Watt-hour Meter Measures One-half the Total Energy of a Balanced Three-phase Circuit.

in a single case, with the moving part of both elements mounted on the same shaft, so that the meter automatically records the algebraic sum of the amounts of energy measured by each element.

One-meter method: If a three-phase circuit is perfectly balanced, the energy expended may be measured with one watt-hour meter whose current coil is connected in one of the phase wires, and whose potential circuit is connected from the same phase wire to the neutral. This method is the same as the three-meter, star-connected method with a perfectly balanced load. The watt-hour meter then measures one-third of the total energy. The potential circuit may also be connected to the middle point of an auto-transformer connected between the other two phases, in which case the meter measures one-half of the total energy (Fig. 130).

The one-meter method is correct for all values of power-factor, as long as the circuit is balanced. Its use, accordingly, should be restricted to

circuits supplying only synchronous apparatus which should be carefully tested for balance. On commercial distributing circuits it is impossible to maintain a sufficiently balanced condition to obtain accurate results from this method of measurement.

The energy expended in three-phase four-wire circuits having loads tapped between the phases and also from any phase to the neutral can be accurately measured only by the three-meter, star-connected method (Fig. 126 above). Instead of three watt-hour meters,

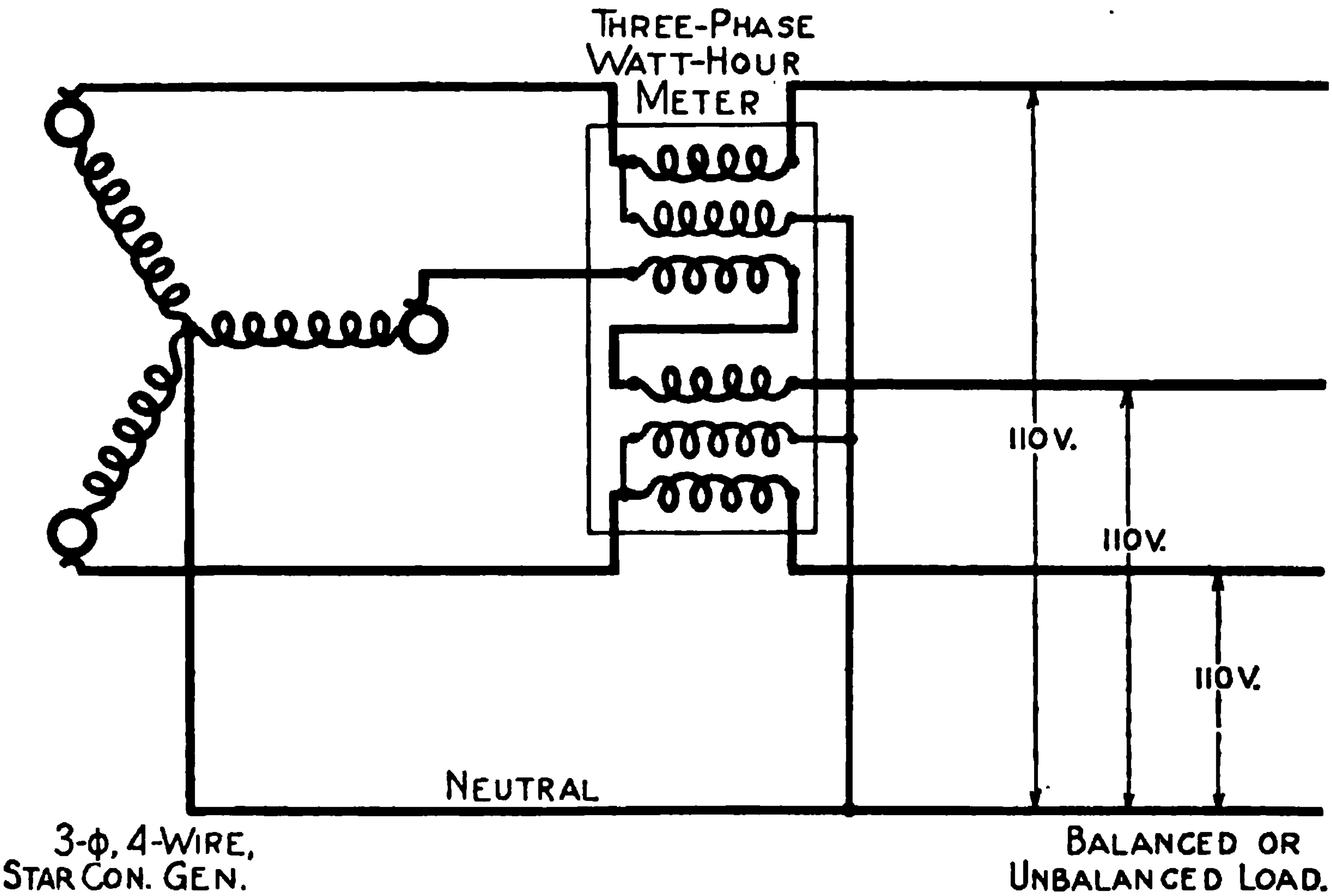


FIG. 131.—Measurement of Energy Delivered in a Three-phase, Four-wire Circuit with Three-phase, Four-wire Watt-hour Meter.

a single, three-phase, four-wire meter, depending on the same principle, may be used to measure the energy expended in a three-phase, four-wire circuit. This meter consists of two potential elements connected from two different phase wires to the neutral, each influenced by the current coil of the phase in which it is connected, and also by one of two coils connected in the third phase wire, the two coils in the third wire being connected in series. As the potentials in the two phases are always displaced by 120 degrees from each other, and from the potential of the third phase, their resultant will be equal and opposite to the potential of the third phase, and consequently will

have the same effect on the two current coils in that phase as the third potential would have, acting directly on one coil when the coils are properly connected for polarity. The same result, therefore, is obtained from this meter as would be from three meters connected one in each phase, provided the potentials are balanced (Fig. 131).

In place of a three-phase, four-wire meter, a three-phase, three-wire meter can be used, connected in circuit by means of current transformers, as shown in Fig. 132. It will be seen that the reversed

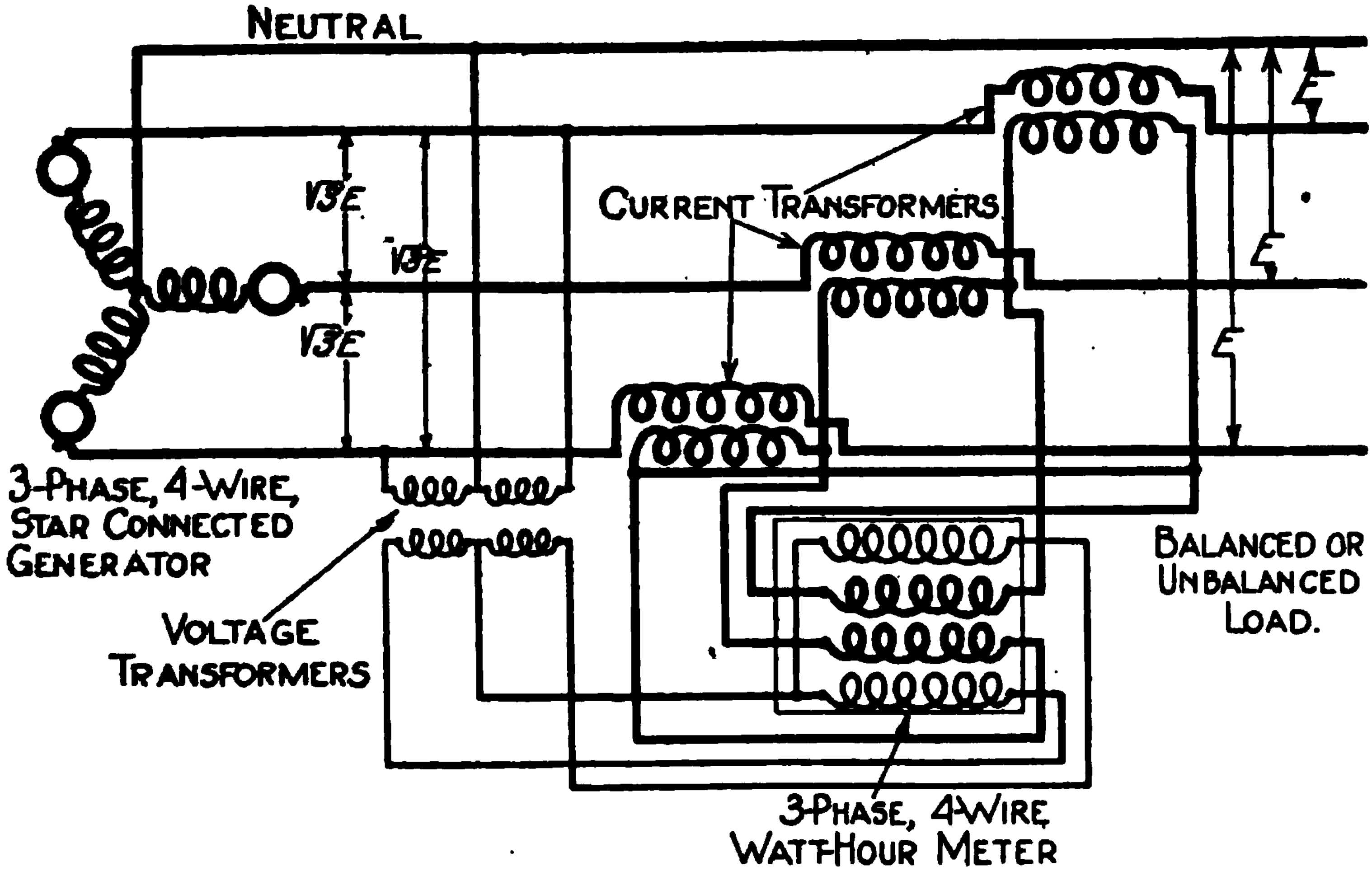


FIG. 132.—Measurement of Energy Delivered in a Three-phase, Four-wire Circuit with Three-phase, Three-wire, Watt-hour Meter and Instrument Transformers.

current from the transformer in the third phase is passed through both the current coils of the meter, and the same result obtained as in the four-wire meter in which the current of the third phase passes through separate coils.

These meters are accurate only on balanced voltages. A three-phase, four-wire, three-element meter is made for use on circuits having unbalanced voltages.

Single and three-phase loads of the same line voltage may be connected both together on the same meters and will be accurately measured by any of the foregoing methods, which are given as correct on unbalanced loads.

For **measuring the energy expended in a three-phase, three-wire**

circuit, from which also is taken single-phase current at one-half the potential of the circuit by a neutral tap from one of the transformers, it is necessary to use a separate single-phase meter in addition to the three-phase meter, as shown in Fig. 133.

It would be possible to measure a non-inductive load, tapped off in the above manner, together with the three-phase load, with a three-phase meter by connecting the single-phase load from one phase to the middle point of the transformer between the phases in which the meter coils are inserted, if the angle of displacement be-

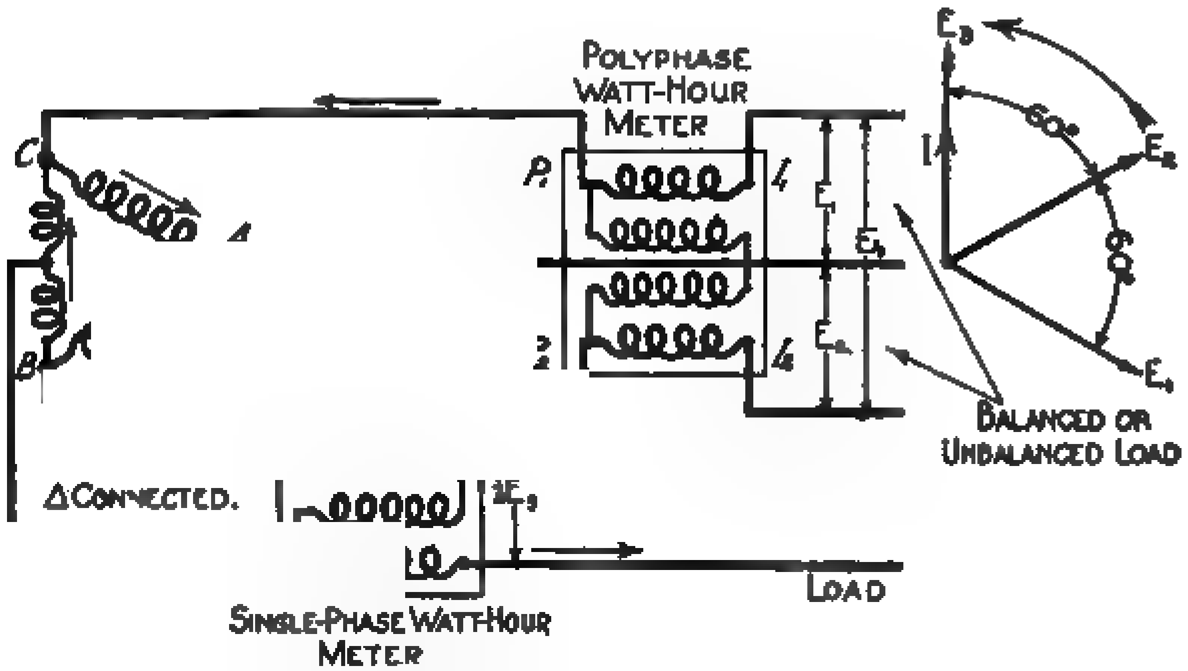


FIG. 133.—Measurement of Energy Delivered in a Three-phase, Three-wire Circuit, from which, also, is taken Single-phase Current at One-half the Potential of the Circuit.

tween the potential in the meter and the single-phase current through the meter were exactly 60 degrees, the cosine of which is .50, so that the meter would measure but one-half the product of the single-phase current and line potential. In that case, we would have the following:

Let I = current on the single-phase circuit.

Let $\frac{E_3}{2}$ = voltage from C to middle point of CB, which is, the voltage on the single-phase circuit.

Then E_3 = voltage CB, between phases.

The load on single-phase circuit $= \frac{E_3 I}{2} \text{Cos } \phi = \frac{E_3 I}{2}$ for non-inductive load.

Power indicated by meter $= 2\frac{E_s I}{2}$ Cos $60° = \frac{E_s I}{2} =$ load on single-phase circuit.

This condition, however, cannot be attained. Even with a non-inductive load, the voltage triangle of the phases will be distorted by the reactance in the transformer winding changing both the phase angle and the voltage *AB*, or E_s, as shown by dotted lines on Fig. 134, the reactance voltage leading the current by 90 degrees.

The error resulting from the distortion of the angle from 60 degrees will be much greater than that due to the higher voltage on *AB* phase, and the errors are in the same direction.

With the inductive loads, an additional error is introduced due to the initial out of phase relation between the current and the potential on the meter.

Owing to the fact that the above method might seem at first to be accurate, and that the extent of the errors which would arise may not be appreciated, let us consider a case in which the current in the single-phase circuit lags 5 degrees behind the potential.

Neglecting the voltage error mentioned above, the load on the single-phase circuit $= \frac{E_s I}{2}$ Cos 5 degrees.

$$= .996\frac{E_s I}{2}$$

$$\text{Power indicated by meter} = 2\frac{E_s I}{2}\ \text{Cos 55 degrees.}$$

$$= 2\frac{E_s I}{2} \times .574.$$

$$= 1.148\frac{E_s I}{2}$$

Percentage of accuracy of method $=$ 115.3 per cent, or the ratio of above measurement to actual load.

The magnitude of this error is due to the fact that the cosine of the angle of displacement changes much more rapidly for the same change in angle at a power-factor of .50 than at unity power-factor. This error increases rapidly with decrease in power-factor, and the meter will run fast or slow, depending on the phase rotation of the system and the phase to which the single-phase circuit is connected.

To prove the amount of these errors, a test was made on one

transformer between *A* and *B* phases, supplying a current of 40 per cent of the rating of the transformer between its neutral and one side of the single-phase circuit. On non-inductive load, the measurement with connections as shown was 119.0 per cent of the correct load, the error being due to the impedance of the transformer alone. With a power-factor of about 99.7 per cent the measurement was 133.6 per cent of the correct load, showing an additional increase of 12.3 per cent of the previous registration, due to the slight change in power-factor. This power-factor is about that usually obtained in lighting circuits, so that the method cannot be considered as even approximately correct.

The power-factor of a balanced, polyphase circuit is defined as the power factor of each of the receiving circuits. In the case of an

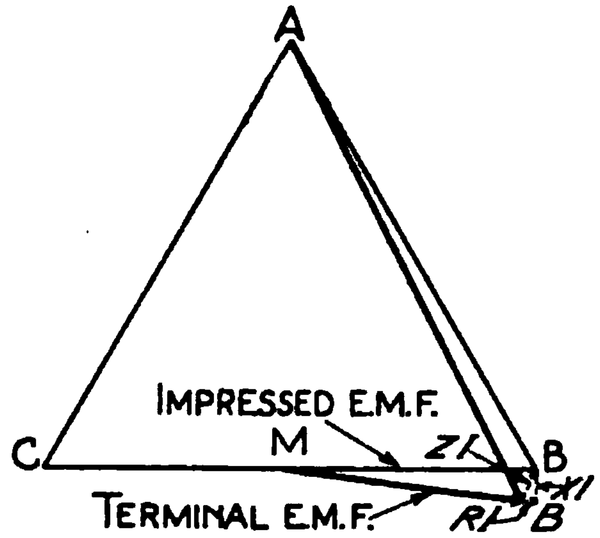


FIG. 134.—Diagram showing Distortion of Voltage Triangle by Reactance in Transformer Winding.

unbalanced, polyphase circuit, the power-factor of each of the receiving circuits should be considered separately.

When the power being expended in a polyphase circuit is measured by one wattmeter in each phase, as in the case of the two-phase circuit, or the three-meter method for a three-phase circuit, the power-factor of any circuit is equal to the watts indicated by the wattmeter in the circuit, divided by the product of the voltage across the potential circuit and the current in the current coil of the same wattmeter.

In the case of a balanced, three-phase circuit, where the two-meter method is used, the readings of the two wattmeters will be unequal when the power-factor is less than unity. The power-factor may be determined from the reading of the two wattmeters without measuring the voltage, or current, of any of the circuits, using the following formula:

$$\tan \phi = \sqrt{3}\frac{P_1 - P_2}{P_1 + P_2}$$

where ϕ = angle of lag, or

$$\text{Cos } \phi = \frac{1}{\sqrt{1 + 3\left(\frac{P_1 - P_2}{P_1 + P_2}\right)^2}}$$

P_1 = reading on wattmeter indicating the larger amount of power.
P_2 = reading on wattmeter indicating the smaller amount of power.

Both the angle of lag and the power-factor can be found, without taking volt-ampere readings, by the following method, proposed by Mr. B. D. Frankenfield in the "Wisconsin Engineer":

"In the two-wattmeter method of measuring power in a balanced three-phase circuit, the following conditions obtain:

"(a) One wattmeter will read zero if the angle of lag between the pressure and the current is equal to sixty degrees, and the power in the circuit is represented by the reading of the other instrument.

"(b) When the angle of lag is less than sixty degrees, the power in the circuit is obtained by adding the two readings.

"(c) When the angle of lag is greater than sixty degrees, the difference in the readings represents the power in the circuit.

"It is also similarly true that in the two watt-hour meter method of measuring energy in a balanced three-phase circuit, the following conditions obtain:

"(a) One watt-hour meter will not rotate, due to the torque being zero, if the angle of lag between the pressure and the current is equal to sixty degrees, and the energy consumed in the circuit is represented by the registration, for the given interval, of the other watt-hour meter.

"(b) When the angle of lag is less than sixty degrees, both watt-hour meters will run forward, and the energy consumed in the circuit is obtained by adding the two registrations for the given interval.

"(c) When the angle of lag is greater than sixty degrees, one watt-hour meter will run forward and one will run backward, and the difference between, or algebraic sum of, the two registrations represents the energy consumed in the circuit.

"In three-phase, two-element watt-hour meters, as explained above, the proper algebraic summation of the torque on both ele-

ments is taken care of by the combined moving element feature of the design.

"This is true whether the lag be positive or negative.

"To prove this theorem, we will assume a specific case of star-connected induction motor. It holds equally well for delta connection, but it is thought better to take a specific case than give a general proof.

"The connections of the wattmeters for the measurement of power are shown in Figs. 129 and 135 in the corresponding vector dia-

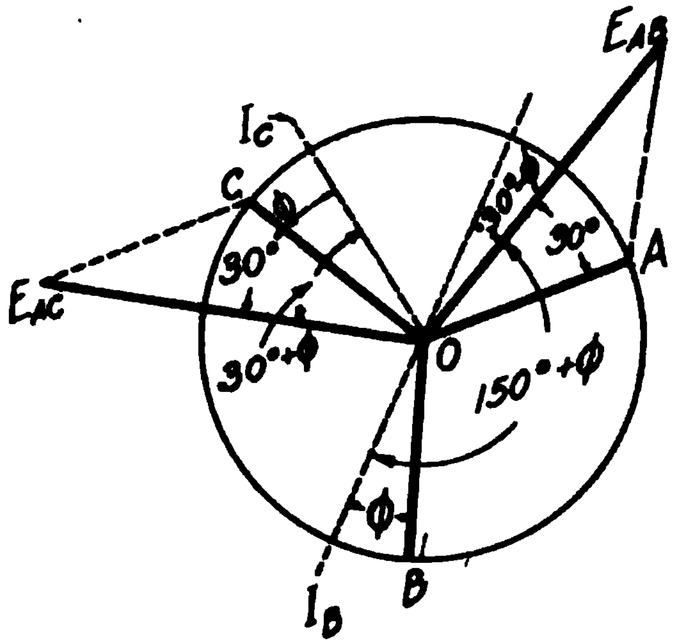


FIG. 135.

gram. OA, OB and OC represent the maximum e. m. fs. on windings A, B and C respectively. The instantaneous pressure will then be,

$$e_A = \sqrt{2}\, E \sin \phi,$$
$$e_B = \sqrt{2}\, E \sin (\phi - 120°),$$
$$e_C = \sqrt{2}\, E \sin (\phi - 240°),$$

where E is the effective e. m. f. on one coil.

"First, consider the meter W_1. The instantaneous pressure impressed on its potential coil will be 30 degrees in advance of OC, and its value will be,

$$e_{AC} = \sqrt{3}\sqrt{2}\ E \sin (\phi - 240° + 30°)$$
$$= \sqrt{3}\sqrt{2}\ E \sin (\phi - 210°).$$

The current in the current coil will be

$$i_C = \sqrt{2}\, I \sin (\phi - 240° - \phi),$$

where I is the effective current in one of the mains and ϕ is the angle of lag.

"The phase difference of current and e. m. f. is then,

$$(\theta - 210^\circ) - (\theta' - 240^\circ - \phi) = 30^\circ + \phi.$$

Hence the component of effective e. m. f. in phase with the current is,

$$\sqrt{3}\, E \cos (30^\circ + \phi)$$

and the power as indicated by wattmeter W_1 will be

$$P_1 = \sqrt{3}\ IE \cos (30^\circ + \phi) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (a)$$

When $\phi = 60^\circ$, $P_1 = 0$;
When $\phi < 60^\circ$, $P_1 =$ a + quantity;
When $\phi > 60^\circ$, $P_1 =$ a — quantity.

"This means that, as the angle of lag passes through the value 60°, the terminals of the pressure coil of our instrument must be reversed, or the needle will disappear on the zero end of its scale, or in the case of a watt-hour meter it will start to run backward.

"Now, considering the wattmeter meter W_2, we have the pressure from A to B leading OA by an angle of 30° and

$$e_{AB} = \sqrt{3}\sqrt{2} E \sin (\theta + 30^\circ).$$

The instantaneous current is, in this case,

$$i_B = \sqrt{2}\ I \sin (\theta - 120^\circ - \phi);$$

and the phase difference between e. m. f. and current is,

$$(\theta + 30^\circ) - (\theta - 120^\circ - \phi) = 150^\circ + \phi.$$

The component of effective e. m. f. in phase with the current is

$$\sqrt{3}\ E \cos (150^\circ + \phi)$$
$$= \sqrt{3} E \cos (30^\circ - \phi).$$

Note: The supplement of $(150^\circ + \phi)$ is taken because in practice $(150^\circ + \phi)$ would be an obtuse angle, and this would give a negative sign which has no practical significance, as the instrument would be connected to read positive under any circumstances. All that we need to prove is that the reading does not change sign within the limits of $\phi = 0^\circ$ and $\phi = 90^\circ$. $(30 - \phi)$ is the acute angle between the vectors of current I_B and pressure E_{AB}.

"The power-factor as indicated by the instrument W_2 is

$$P_2 = \sqrt{3} IE \ \cos (30^\circ - \phi) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (b)$$

When $\phi = 60^\circ$, $P_2 =$ a + quantity;
When $\phi < 60^\circ$, $P_2 =$ a + quantity;
When $\phi > 60^\circ$, $P_2 =$ a + quantity.

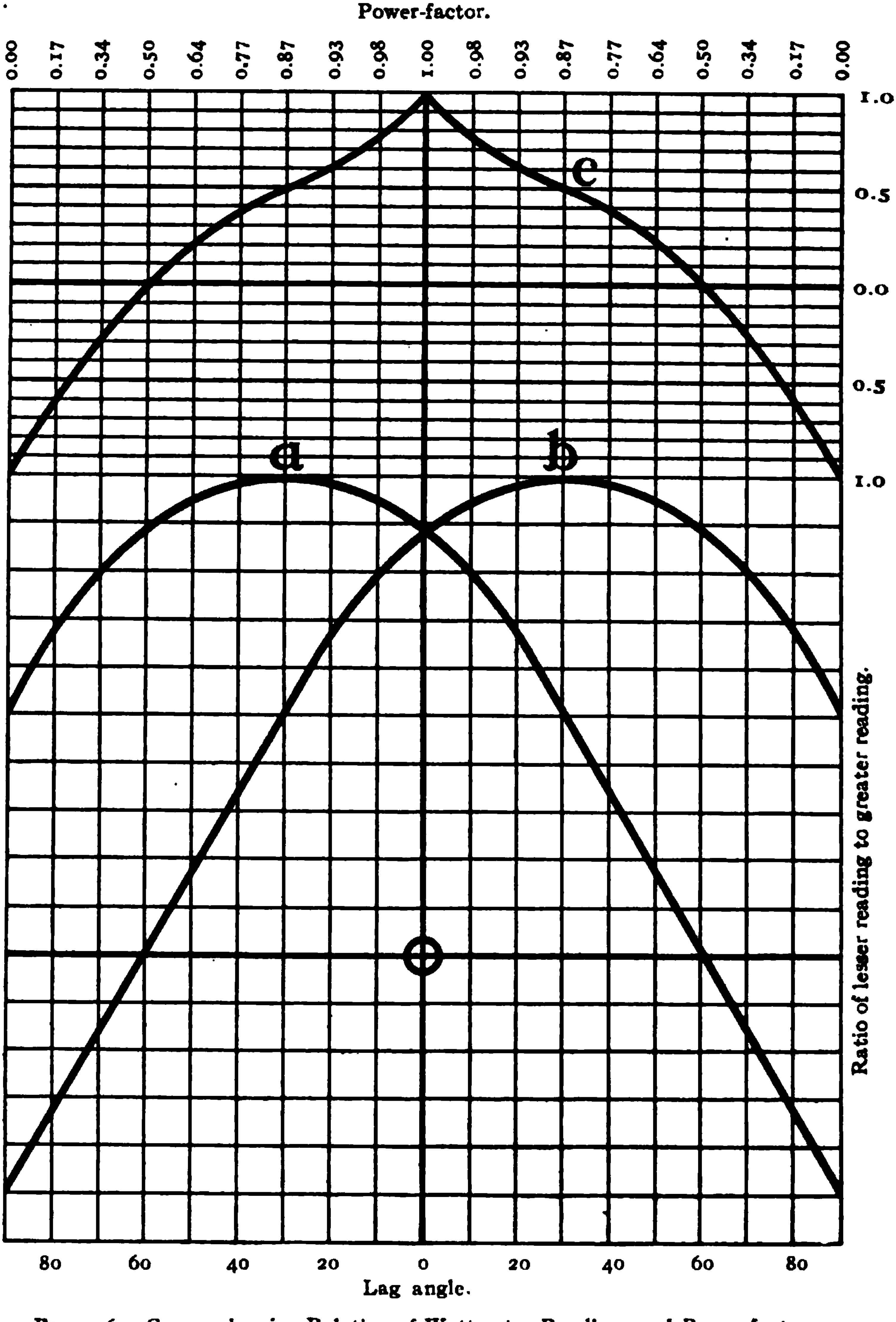


FIG. 136.—Curves showing Relation of Wattmeter Readings and Power-factor.

"This shows that the instrument will read positive for all values of ϕ met in practice, ninety degrees being the value of ϕ, which gives a zero power-factor.

"An inspection of equations (a) and (b) shows that our theorem holds for negative values of ϕ, and that the terminals of wattmeter W_2 must be reversed at $\phi = 60°$, while those of W_1 need not be changed throughout the entire range. This is the case of a capacity load.

"Equations (a) and (b) may be plotted as in Fig. 136, where ϕ is measured along the axis of X and the corresponding relative values of P_1 and P_2 along the axis of Y. Curves (a) and (b) correspond to equations (a) and (b) and are two sinusoids 60 degrees apart. Two simultaneous ordinates for any value of ϕ will have lengths proportional to the readings of the wattmeters. The third curve (c) represents the ratio of the lesser reading to the greater. The power-factor, plotted on the upper scale, is equal to cos ϕ.

"We will now work a practical example, using these curves.

"Suppose we desire to know the relation between power-factor and load of a certain three-phase motor. Running light, the instruments read 1,340 and 895 watts respectively. The ratio of the less reading to the greater is 0.67. First of all we know that the lag is positive and we find from curve (c) that there are two positive values of ϕ which will give ordinates in this ratio. One gives a high power-factor and the other a lower one. Our judgment tells us that as the motor is running light, the power-factor is low, and we find that the lag is 82 degrees and the power-factor 13 per cent. We also see from curves (a) and (b) that the number of watts expended in the circuit is equal to the difference of the readings, or 445.

"When the machine is given another increment of load the power-factor is obtained in the same manner, and the difference of the readings for each increment of load will represent the input until a power-factor of 50 per cent (corresponding to a lag of 60 degrees) is reached, when one instrument will read zero. Its pressure terminals must then be reversed and the sum of the readings will represent the input to the end of the test.

"If a person has no idea of the power-factor on the circuit tested, as might often be the case, he can vary the load until one instrument reads almost zero. If the reading of the other decreases at the same time, the power-factor is greater than 50 per cent and the readings should be added; if it increases, the power factor is less than 50 per cent, and the difference of the readings represents the power. This is readily seen by an inspection of the curves.

"Another instructive point which this diagram brings out is that

if both instruments indicate the same amount of power, the lag is either 0 degrees or 90 degrees, and the circuit is either in resonance, or is entirely wattless."

For reasons of convenience and economy in **distribution, power** may be transmitted by means of an alternating current of high potential and transformed to a current of low potential, and correspondingly larger amperage at the consumer's premises, **by means of load**

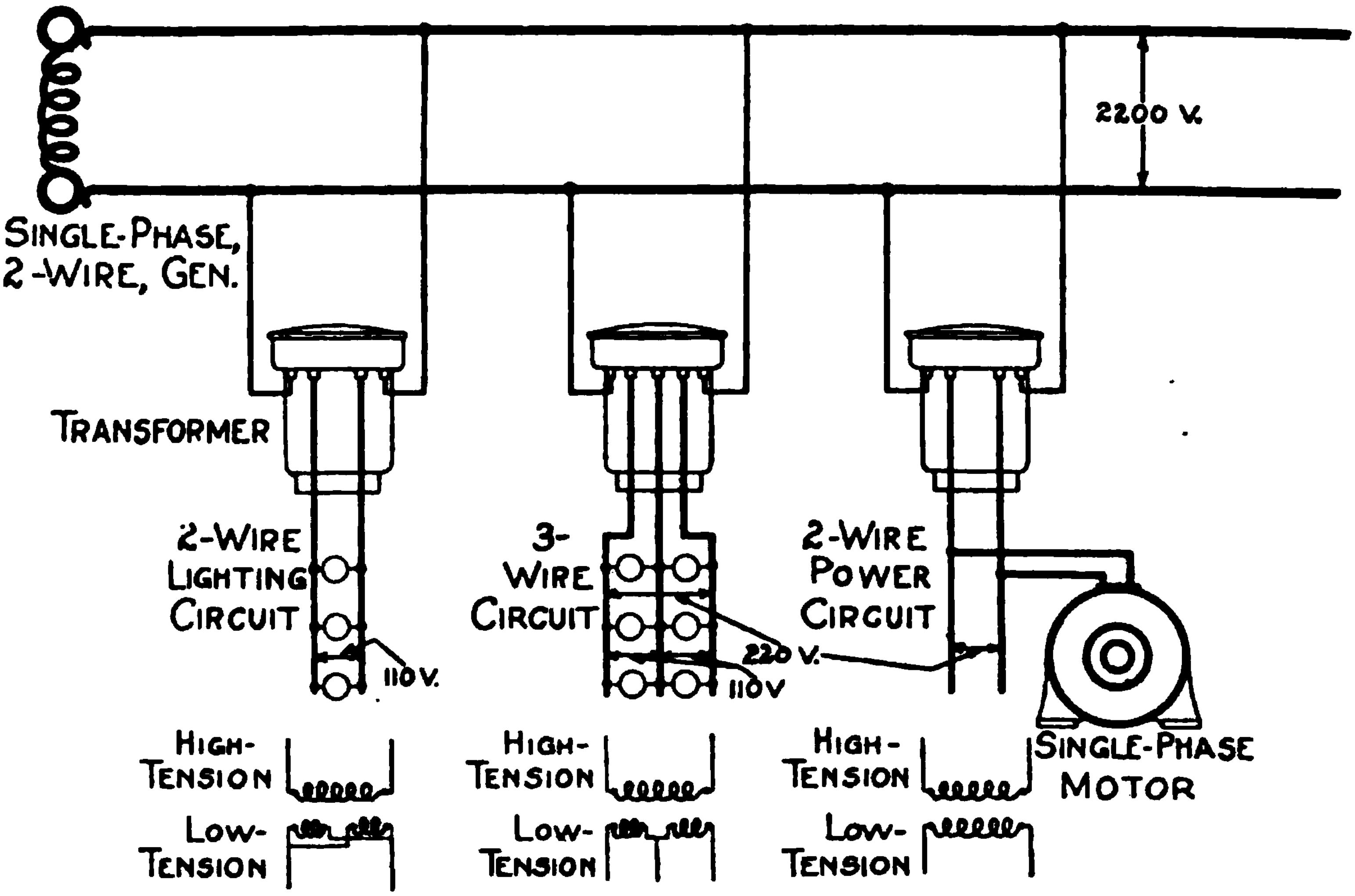


FIG. 137.—**Single-phase System of Distribution with Load Transformers.**

transformers, Figs. 137 to 143 inclusive. **Instrument transformers are used,** for reasons of safety and convenience, **in measuring energy** in circuits of high voltage or heavy amperage, and the same **general considerations** are applicable to transformers used for one purpose or the other.

Fig. 144 shows an alternator, star connected, supplying power to several **banks of transformers.** Bank No. 1 is **star-star** connected, bank No. 2 **star-delta** connected, bank No. 3 **delta-star** connected, bank No. 4 **delta-delta** connected, and bank No. 5 **open-delta** connected. These are the five general arrangements of transformer connections. It is necessary in connecting transformers in three-phase that they be joined together in proper relation to each other. For the star-star connection (bank No. 1)

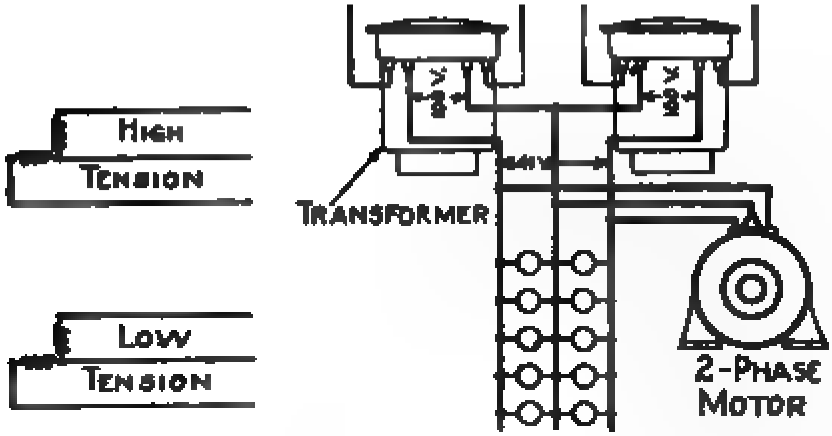


Fig. 138.—Two-phase, Three-wire System of Distribution with Load Transformers.

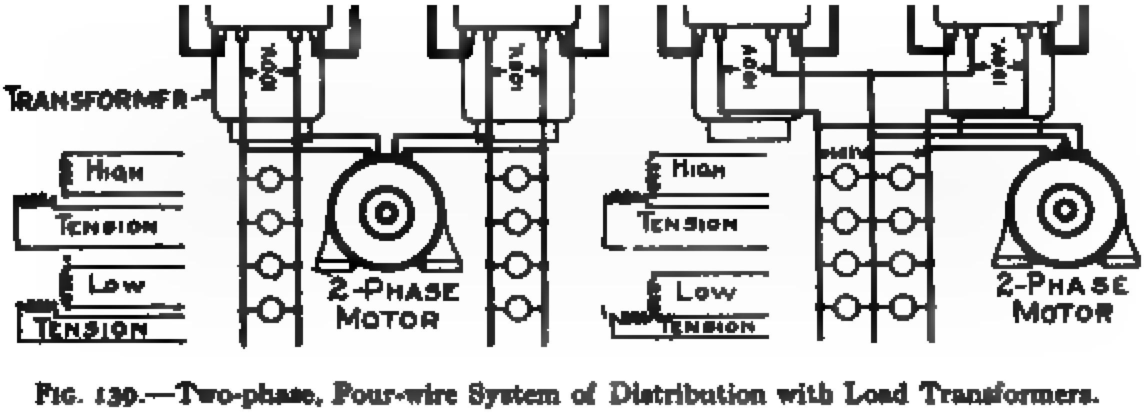


Fig. 139.—Two-phase, Four-wire System of Distribution with Load Transformers.

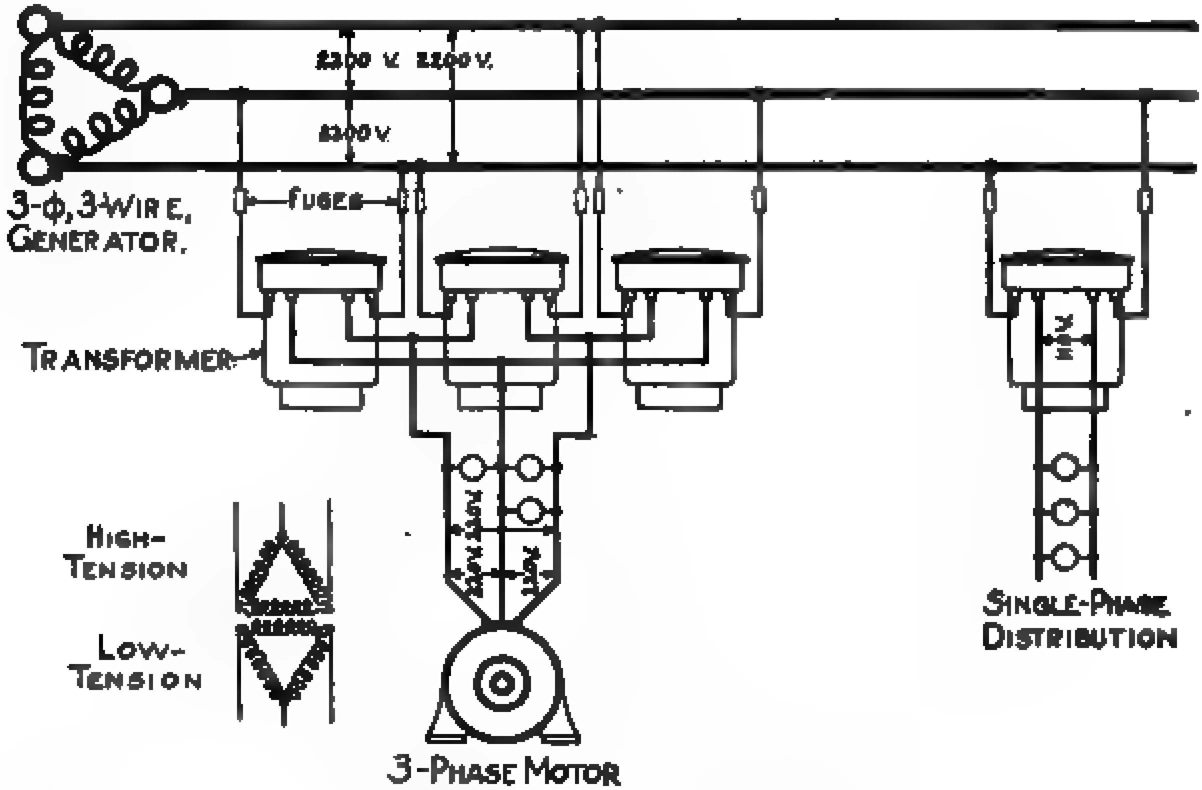


FIG. 140.—Three-phase, Three-wire System of Distribution with Load Transformers Connected Single- and Three-phase on Same System.

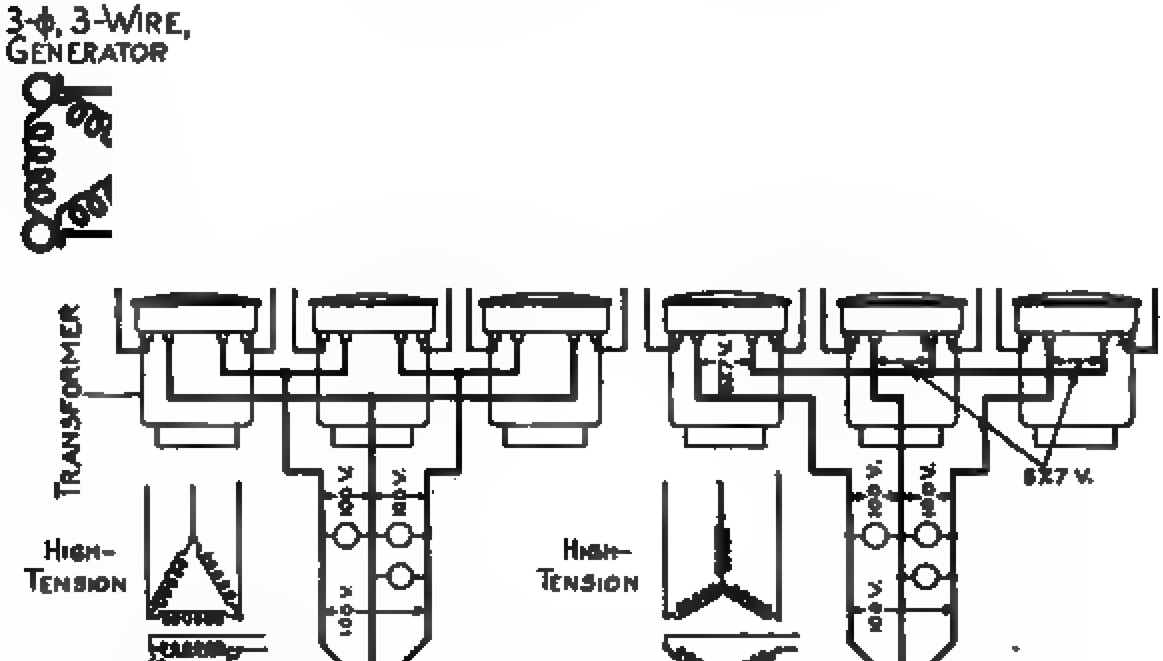


FIG. 141.—Three-phase, Three-wire System of Distribution with Load Transformers Connected Delta-delta and Star-star

three of the ends of the windings should be joined together as shown, and the other end of each transformer winding connected to the mains as shown. Assume the instantaneous currents in the high-tension side to flow away from the neutral, or toward the neutral, as shown by the arrows. The low-tension side must be connected, so that their instan-

3-PHASE MOTOR

FIG. 142.—Three-phase, Three-wire System of Distribution with Load Transformers Connected Delta-star.

taneous currents will all also be made to flow either away from or toward the neutral.

In connecting transformers in delta, assume the instantaneous currents to flow around the delta in the one direction; that is, join all the transformers, so that the windings are in series. For instance, the high-tension sides of bank No. 2 are star connected. The current is assumed to flow out from the neutral, as shown by the arrows. On the low-tension side the induced currents will be in the directions of the arrows, as indicated. In order, therefore, to properly connect the low-tension side in delta, join the transformers so that the three instantaneous currents are in series, all flowing in the same direction around the closed delta.

In three-phase systems abnormal conditions may exist that are not dependent upon the loads connected to the system. They result from certain methods of connecting transformers (or similar apparatus requiring a magnetizing current) and are known as **harmonic** effects. (Figs. 29 to 36 inclusive, Chapter II.)

To illustrate this, consider transformer bank No. 1, shown in Fig. 144. This bank of transformers is so connected that the voltage

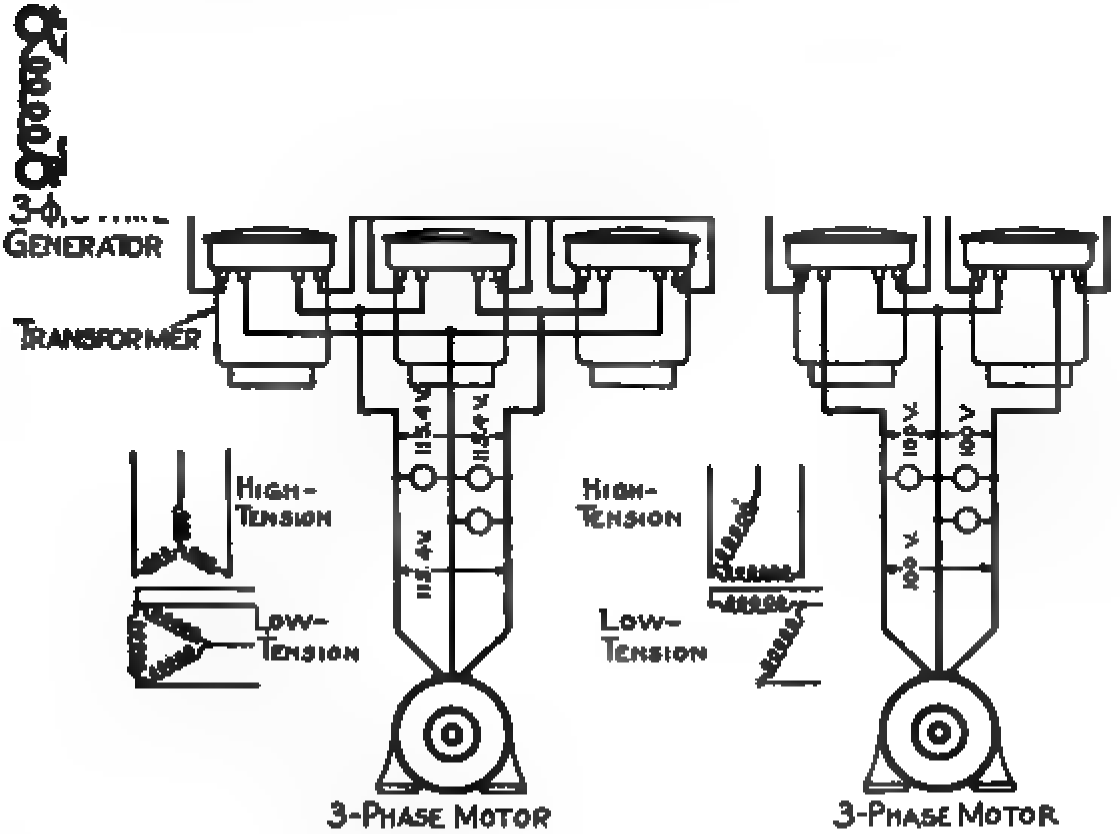


FIG. 143.—Three phase, Three-wire System of Distribution with Load Transformers Connected Star-delta and Open-delta.

across each transformer is not actually the line voltage divided by the $\sqrt{3}$, but is somewhat higher. This distortion is due to the fact that the third harmonic component of the magnetizing current has no return to the transformers. This third harmonic current is a current of triple frequency normally present in current supplied by commercial generators. (Fig. 36, Chapter II.)

The fundamental waves of the three phases are shown in Fig. 29, Chapter II. The triple frequency waves are also shown in each phase. It is seen that the triple frequency waves in each phase are in phase with each other; and, therefore, do not, algebraically, add up to

zero. Since the sum of the currents in a three-phase system must equal zero, the third harmonic currents cannot flow and maintain this condition. As a result, the transformers do not receive their normal value of magnetizing current, and the voltage wave of each transformer is distorted from the sine wave shape by the presence of a prominent third harmonic. It is this distortion of the e. m. f. wave that causes the rise in voltage across each transformer of the star-star connected bank in Fig. 144.

To overcome this distortion, it is necessary to provide a path that

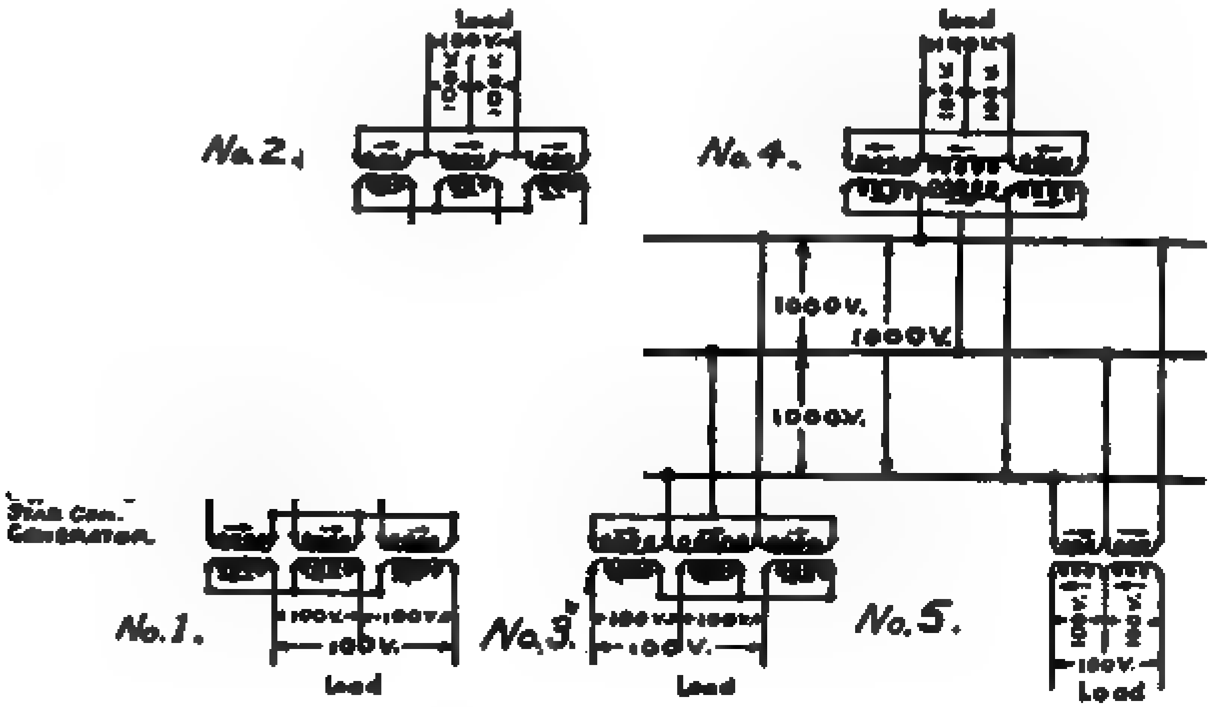


FIG. 144.—Diagram of Various Methods of Connecting Transformers on a Three-phase System of Distribution

will permit the triple harmonics to flow and neutralize themselves. It can be done in two ways as follows:

(1) By connecting the neutral of the transformers to the neutral of the generating system, through a metallic conductor, or the ground, as discussed later.

(2) By connecting either the high-tension side or the low-tension side of the transformer in delta.

By completing the neutral connection from generator to transformers, the third harmonic can then flow over the fourth wire, or connection, and the balance of the system will be restored. In like manner by connecting one side of the transformers in closed delta,

the third harmonic will flow around the closed delta. In either method, the balance of the system is restored and the third harmonic in the voltage wave disappears. Transformer bank No. 2 (Fig. 144) will operate safely, since it is provided with a closed delta.

Grounding the neutral point of the star connected transformers, and the generator neutral, might establish a balance, as intimated above, but this depends upon whether the resistance of the ground between the neutrals is sufficiently low to act as a return wire.

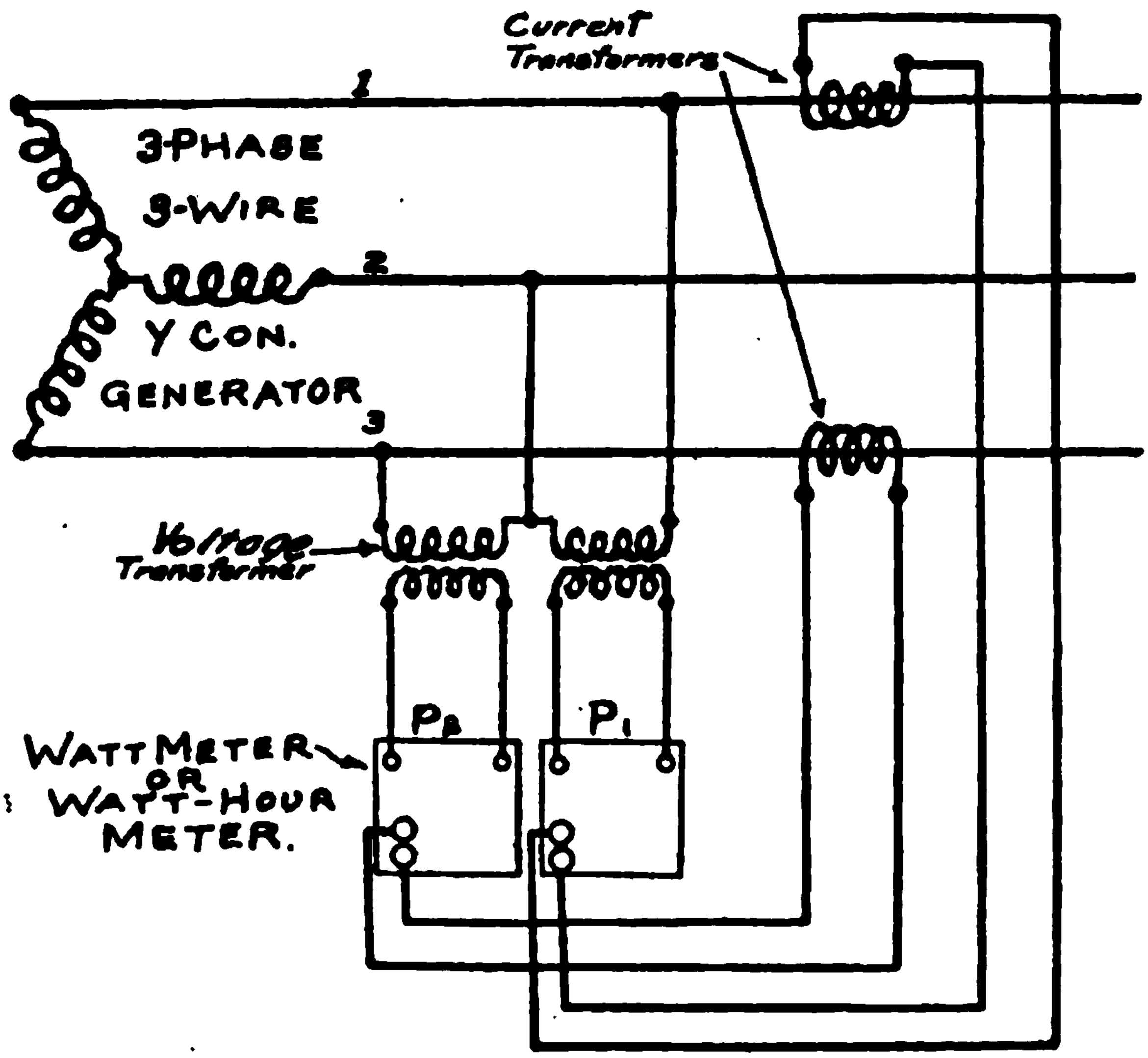


FIG. 145.—Measurement of Power, or Energy, Delivered in a Three-phase, Three-wire Circuit with Instrument Transformers and Two-meter Method.

Where this system is used on three-phase banks of load transformers, the two-meter method will not measure the power, because the system becomes equivalent to a four-wire circuit.

In the case of alternating current circuits carrying large currents, or operating at high voltages, transformers are used to reduce the values of voltage and current applied to the meter in a fixed ratio, which will bring them within the range of a meter of ordinary construction (Chatper V). Current and voltage transformers should be employed in all high voltage circuits for purposes of insulation, inde-

pendently of whether the value of current requires them, and also on account of the greater safety, flexibility and convenience secured by their use. Care must be taken in connecting these transformers that the direction of flow of current in the low-tension circuit through the watt-hour meter is the same as if the high-tension circuit were connected directly (Fig. 45 and explanation in Chapter II).

The same precautions previously stated in regard to load transformers must be observed when connecting potential transformers for use with instruments or watt-hour meters on three-phase circuits.

In the two-meter method of energy measurement, the voltage trans-

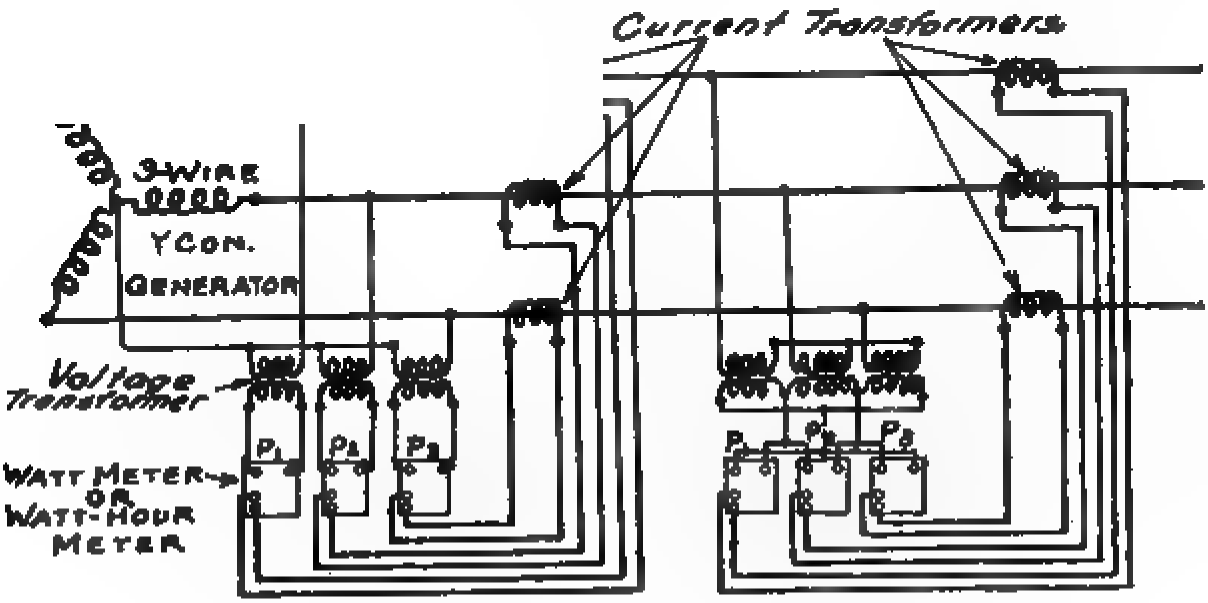


Fig. 146.—Measurement of Power, or Energy, Delivered in a Three-phase, Three-wire Circuit with Instrument Transformers and Three-meter Method.

formers used to step down the voltages for the watt-hour meter potential coils are tapped across the mains, as shown in Fig. 145.

In this case each transformer can be considered as being on a single-phase circuit, the middle wire acting as a common return for both transformers. Since this is not a condition of three-phase connections, affected by third harmonic currents, each transformer will receive its proper magnetizing current and the conditions will be normal, as far as harmonic effects are concerned.

In the three-meter method of energy measurement the voltage transformer must be connected star on the high-tension sides (Fig. 146). The reason is evident, since the transformer high-tension windings must have the same voltage across them as the watt-hour meter potentials would have if connected directly in circuit. It will not do

to connect the high-tension sides delta and the low-tension sides star, since this will change the phase relation of the potentials.

Therefore, it is essential that the high-tension sides be connected star. If the low-tension sides are connected star also, as shown in bank No. 1, then the neutral of the high-tension star must be connected to the neutral of the generating system to maintain a normal potential. If the low-tension sides are connected delta (bank No. 2, Fig. 144), it will not be necessary to connect the neutral of the high-tension side to the generator neutral, since the closed delta preserves the balance. It is important that the delta remain closed during the operation of the system, because if open, the voltage across each transformer will increase appreciably.

As previously stated, this increased voltage, due to the higher harmonics, does not, however, cause any error in the registration of the watt-hour meter, if it is so designed as to be accurate on the higher voltage and altered wave form, since the change in power-factor exactly neutralizes the effect on the watt-hour meter of the higher potential.

This is demonstrated by E. Arnold in Volume I of Die Wechselstromtechnik, page 305.

CHAPTER V

LABORATORY, STANDARDS AND INSTRUMENTS

CHAPTER V

Laboratory, Standards and Instruments

To select a suitable equipment of standards and instruments, and to use them in such a manner as to obtain the best results, is a problem often difficult of solution for those whose opportunities of obtaining information on such subjects have been limited.

The purpose of this chapter is to present to those central station metermen, who have not had specific training in instrument work, some of the principles involved in electrical measurements; the features of the designs of various types of instruments used in connection with the maintenance of watt-hour meters, and the combined results of the experience of many operating companies as regards the selection of suitable standards and general laboratory practice in their use. Some of the data set forth may be regarded by many as academic, but it is believed that the average man intrusted with the care of instruments will find material which will prove helpful.

Concrete standards of the practical units of the International System are preserved by the United States Government in the Bureau of Standards of the Department of Commerce and Labor, at Washington, D. C.

This institution is the final authority in the United States for the values of electrical standards. Other laboratories maintain standards in agreement with those of the Bureau of Standards, at Washington, and like it, are prepared to measure and certify to the values of suitably constructed standards submitted for this purpose.

It is not practical for any operating company to submit all its instruments to such laboratories at intervals frequent enough to insure unimpaired accuracy; so, for this reason, it is necessary to provide primary standards which are in agreement with those of the National Bureau, and to use them in calibrating secondary standards and working instruments.

The equipment of a laboratory suitable for central station meter work is dependent upon many factors. Consideration should be given to the money available, the class of current generated, and the

facilities offered by independent testing authorities of recognized value.

Companies located within reasonable distance of the National Bureau of Standards at Washington, D. C., the Electrical Testing Laboratories at New York, the laboratories of instrument makers or of universities, etc., may not require so extensive an equipment as those not so conveniently located, as the primary standards of these institutions may be used to check the secondary standards of operating companies.

As to **the expenditure involved** in furnishing suitable testing facilities and instruments, much depends upon the size of the company and the character of the service. A limited amount of equipment, fully adequate to give reliable results in a smaller company, will not be sufficient for one of larger size; while companies supplying both alternating and continuous current require instruments of different style from those necessary in cases where but one class of service is supplied.

The selection of instruments best adapted to meet the requirements of a particular case, is a very important matter, and should receive careful attention. The most suitable types and ranges must be determined by the kind of service for which they are to be used, and the degree of accuracy required.

The reliability of any instrument depends upon the type, design, materials and methods of construction. While the basic principle of all instruments of a particular class is the same, it is frequently true that there are features of construction and material which may be peculiar to the designs of certain manufacturers, and absent in those of another. These features may or may not enhance the value of an instrument, and, while the effect of some is very apparent, others—and particularly those which may be detrimental—can only be detected by a critical examination and test. Therefore, in the case of primary standards, it is best, prior to purchase, to submit the instruments under consideration to a capable testing laboratory for examination and certification of accuracy. This precaution affords the purchaser insurance against defective instruments, and promotes confidence in the use of those instruments to which the accuracy thereof has been certified.

In general, instruments operating upon a null or balance principle are more reliable than deflection instruments (Figs. 147 and 148). The potentiometer, and instruments of the Kelvin balance type, operate on this principle, while direct reading voltmeters and ammeters are deflection instruments. Null instruments are required for work of the highest

possible accuracy, but are expensive; slow to operate, and require steady current and voltage In the case of the potentiometer, a storage battery supply is essential. Deflection instruments are much cheaper, quicker to operate, and do not require especially steady conditions (Fig. 149).

Whatever type is selected should be the best obtainable in design

FIG. 147.—Watt Dynamometer for Use on Alternating Current. The Movable Element is Made of Two Coils, One Supported Above the Other, Through Which the Current Flows in Reverse Directions so as to Make it Astatic with Reference to the Earth's Field Leeds and Northrup.

and construction; due consideration being given to the character of service required. All instruments should be as free as possible from errors due to the effect of temperature, stray fields, vibration, and mechanical imperfections. Indicating instruments should be provided with accurately laid-out scales, the divisions of which are easily readable and the values plainly marked.

Laboratory Equipment.

Fundamental electrical standards are essentially for continuous current. The methods for continuous current standardization are based upon the potentiometer principle which is recognized as the most accurate method for the purpose; reliability being based upon the accuracy and permanence of standard resistances and standard cells.

The primary standards of a central station laboratory remotely located with reference to facilities for independent testing should consist of a potentiometer, standard cells, and standard resistances.

FIG. 148.—Precision Voltmeter, Kelvin Balance Type, for Use on Alternating and Continuous Current. Westinghouse.

With these, the values of electromotive force, resistance and current can be accurately measured in terms of the fundamental units. Accessories to the potentiometer are—a storage cell for supplying the current, a regulating rheostat, volt box, and galvanometer.

Primary standards are not suitable for general use, but should be used for the purpose of checking secondary standards; the latter being those with which the working instruments are compared.

For continuous current service, **the secondary standards** required consist of a laboratory type of continuous current voltmeter, and a millivoltmeter with shunts.

If alternating currrent instruments are to be tested, the secondary standards must be of the transfer type, i. e., those which may be

tested on continuous current and used without appreciable error on alternating current of commercial frequencies. For this purpose it will be necessary to provide a voltmeter, wattmeter and ammeter.

For ordinary voltages a resistance multiplier may be used in connection with the wattmeter or voltmeter, but for potentials in excess of 750 volts, the range should be extended by means of a voltage transformer.

For the measurement of current the capacity of the ammeter need not exceed 5 amperes, as current transformers may be used to extend the range of the instrument to any desired value.

Fig. 149.—Precision Wattmeter, Dynamometer Type, for Use on Alternating and Continuous Current. Siemens and Halske.

For the measurement of alternating current power a wattmeter is required, as the formula—

$$\text{Watts} = \text{Volts} \times \text{Amperes, or}$$
$$P = EI$$

is true only for cases where the power-factor of the circuit is unity.

The **working standards used in calibrating watt-hour meters** consist of portable indicating voltmeters, millivoltmeters with shunts, ammeters, wattmeters, and watt-hour meters known as "rotating standards" (Figs. 150 and 151).

Integrating electrical meters involve the element of time as well as quantity. A **watt-hour meter** gives a reading proportional to the product of the average power and time, or, in other words, to the

energy that has passed through it. Thus, 100 watts for 10 hours, or 10 watts for 100 hours, or 50 watts for 20 hours, are integrated, or summed up, by the register, and indicated as 1,000 watt-hours, or 1 kilowatt-hour, (Chapter III).

In testing watt-hour meters, therefore, it is necessary to accurately measure the time as well as the value of the power that has passed through it.

The master **standard for the measurement of time** should be an accurately regulated clock, with a pendulum beating seconds, having a reliable electrical contact device, by means of which signals can

FIG. 150.—Portable Voltmeter, D'Arsonval Type. for Use on Continuous Current. Weston.

FIG. 151.—Portable Wattmeter.

be sent or relays operated. Instead of a clock, an accurate chronometer contact may be used Stop watches are generally used as secondary and working standards. Automatic relay timing devices connected to the master clock are more accurate than stop watches for use in the laboratory where higher accuracy is desired.

Voltmeters, and **millivoltmeters** with **shunts,** used as **ammeters,** or ammeters, are used in conjunction with **stop watches** for testing continuous current watt-hour meters.

Wattmeters and stop watches are used for testing alternating current watt-hour meters, and **rotating standards** are used for both alternating and continuous current watt-hour meter testing.

A **Wheatstone bridge** affords an admirable means of determining

the resistance of voltmeters, multipliers, the potential circuits of wattmeters, and watt-hour meters.

A **frequency meter** is useful, and, where the testing circuit is supplied by a motor generator set, is absolutely necessary unless the generator is driven by a synchronous motor from a system of known frequency.

A **power-factor meter** may be employed to advantage in certain kinds of tests, though, for most purposes, a voltmeter, ammeter and wattmeter may be used in its stead. The fact that it is less

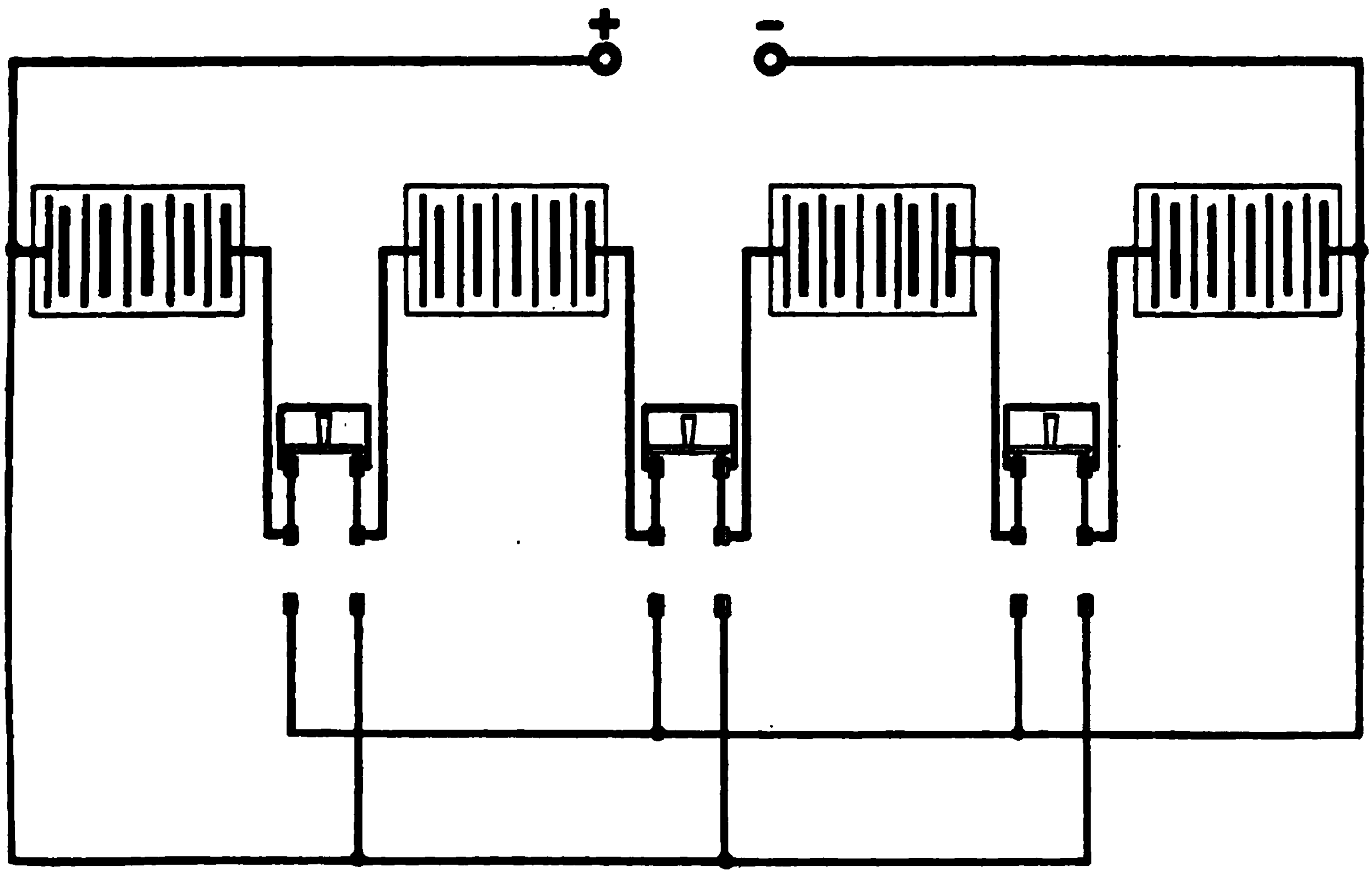


FIG. 152.—Connections for Four Cell Storage Battery, Switches as Shown for Eight Volts, Center Switch Down for Four Volts, all Switches Down for Two Volts.

difficult to read one instrument than to read three is often the determining factor when considering the choice of methods.

In the laboratory a steady testing current is essential. For continuous currents the supply is best obtained from **storage batteries.** For currents up to 1,000 amperes storage cells may be conveniently mounted on a truck, to be wheeled about the laboratory, and particularly in order to permit of their removal to other places for charging; the presence of acid spray in the neighborhood of instruments is undesirable, and this condition is produced when cells are charged in the same room with laboratory instruments.

A convenient **source of potential** in checking voltmeters, etc., is afforded by a bank of small storage cells of 8 to 20 ampere-hours

capacity—the number depending upon the maximum voltage to be supplied, and the capacity depending upon how large a current will be drawn at any time. The cells for supplying potential should be located in a separate room, if possible, and wired to suitable terminals in the laboratory.

The cells used as a **source of heavy current** should be wired to a switchboard having switches so arranged that all cells may be connected in parallel, two halves of the battery in series parallel, or the total number of cells in series. A voltmeter should be provided

FIG. 153.—Motor Generator Equipment with Separate Generators for Supply of Current and Potential.

which will read the voltage of each cell separately or the voltage of the discharge circuit. This assists in determining the condition of individual cells.

A method of arrangement suitable for use with four cells of battery is illustrated in Fig. 152.

The best **resistance for heavy current** consists of metallic resistance strips provided with single pole switches for coarse regulation, and a small carbon rheostat in parallel for fine regulation.

A steady alternating current is best obtained by means of a motor generator. In most cases it is more satisfactory to employ a generator driven by a synchronous motor, since the frequency of the

nected on the same shaft mounted on one base The set is driven at 1,800 r. p. m. by a 7.5 kilowatt, 220 volt, two-phase synchronous motor. The current for testing is obtained from the current generator, which is of 5 kilowatt, 200 ampere, 25 volt capacity. Potential for testing is supplied from either of two exactly similar potential

generators, whose rating is 1 kilowatt, 5 to 10 amperes, 100 to 200 volts. The fields of both potential generators are arranged with a rack and a worm gear, so that they can be rotated through 90 geometric degrees or 180 electrical degrees.

The test board used in conjunction with the above set is wired with two potential buses so that a potential in phase with the current is supplied to one potential bus and a potential of any other desired phase, in order to obtain a power-factor, can be supplied to the other potential bus. The field of the potential generator supplying potential out of phase with the current generator is displaced mechanically by means of the above-mentioned rack and gear.

One used by the United Electric Light & Power Company, of New York, is illustrated in Fig. 154.

This apparatus consists of a 4 pole, three-phase, 15 h.p. synchronous

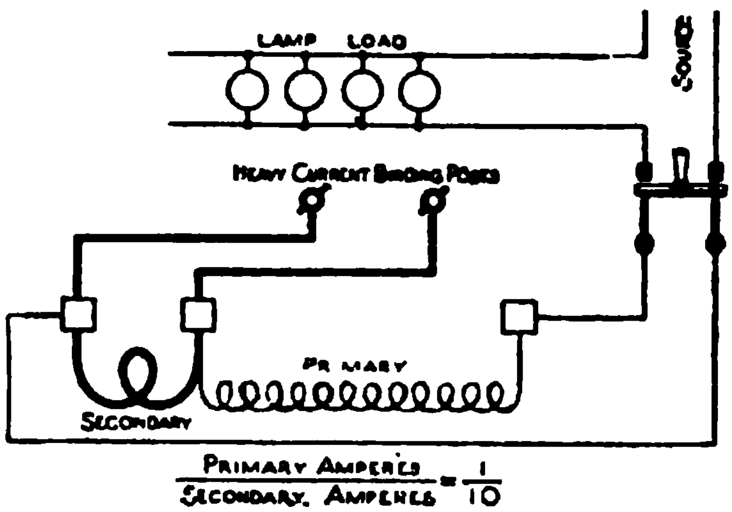


FIG. 155.—Auto-transformer for Obtaining Heavy Alternating Currents.

motor, direct connected to and mounted on the same base with a 10 pole, two-phase, 10 k. v. a. 125 volt alternator.

The armature of the generator is of the closed circuit type of winding, and the fields of both motor and generator are arranged for excitation at 125 or 250 volts.

To supply **heavy currents for alternating current** ammeters and the current coils of wattmeters and watt-hour meters, **transformers** should be provided with the low-tension winding voltage of such value that steps of from two to ten volts may be obtained. The voltage required depends upon the lengths and size of the leads, the drop in each instrument, and the number of instruments to be in circuit at one time.

A series auto-transformer may be used to economize power for heavy current measurement. Such a device is illustrated in Fig. 155.

The standard and instrument under test should be connected in the low-tension circuit.

Under this condition, when a series auto-transformer is used for tests on watt-hour meters, the phase displacement of the current in the low-tension winding effects both the indications of the standard and the instrument under test.

Resistance boxes and rheostats should be provided for the control of voltage and current. Slide resistances are very convenient where fine control is desired, and may be so connected as to provide a ready means of varying voltage when testing voltmeters. Carbon rheostats are satisfactory for current control up to 150 amperes. Carbon tends to

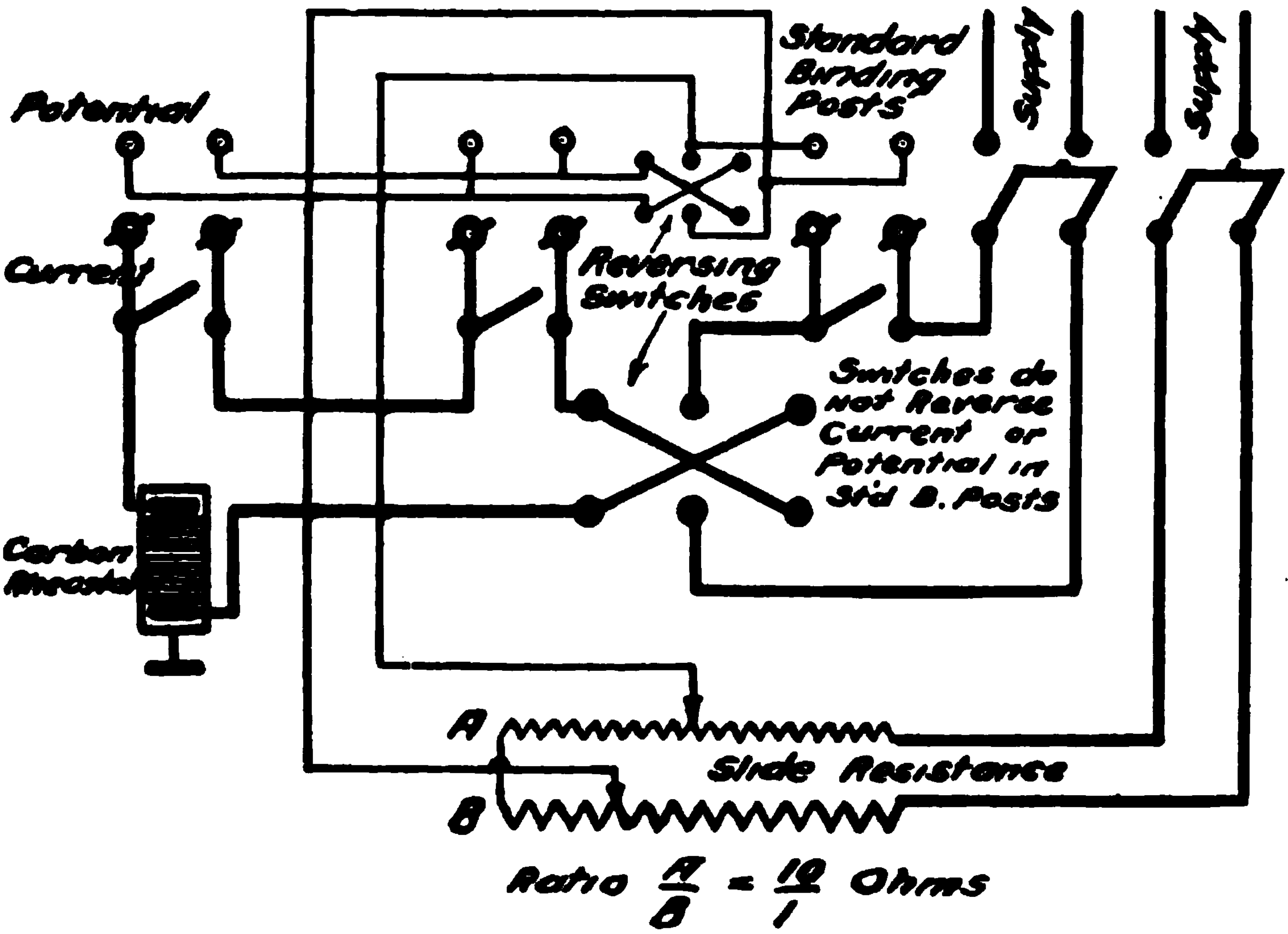


FIG. 156.—Diagram of Circuits for Use in Calibrating Instruments by Means of Primary or Secondary Standards.

lower in resistance with an increase of temperature. For this reason carbon rheostats cannot be set to definite values of resistance.

Testing circuits should be provided with switches, rheostats and binding posts of ample capacity. The wiring should be well insulated and so arranged as to avoid loops. The best plan is to run all wires as close together as possible, and thus neutralize the effect of stray fields in the test circuit.

Fig. 156 illustrates the arrangement of circuits which are well adapted for use in calibrating instruments by means of primary or secondary standards.

The circuit which is intended to be used in testing watt-hour meters should be so arranged that the meter being tested can be compared at low power-factors with a standard of known accuracy.

When a polyphase circuit is available, the meter can be tested under conditions of low power-factor without the use of a load which would actually produce that condition on the line.

Fig. 157 shows an arrangement which may be used on experimental work and for various kinds of single-phase and polyphase tests on watt-hour meters.

A three-wire circuit is used and the power supplied may be either two-phase or three-phase. By referring to the diagram it can be seen that the series coils of the watt-hour meters are connected to the middle line of the circuit, and that there is a lamp board in each of the other sides. A smaller auxiliary lamp board, with slide resistances and switches arranged for series or multiple connection of lamps can be connected to either of the main lamp boards.

Current is supplied to the shunt circuit through a two-point plug *P*, which fits any two of the points in the three-point receptacle. This plug is connected to the testing circuit by means of flexible leads, and may be used as a reversing switch. The three points of the receptacle connect to the three sides of the main line.

A similar plug *P'* and receptacle are provided for switching on the primary of an induction regulator. This regulator has its low-tension winding on a drum which can be revolved through 180 degrees. This gives gradual changes from maximum secondary voltage in one direction to maximum in the opposite direction. It is used as a voltage regulator or phase-shifter, depending on whether the high-tension winding is connected to the same phase as the potential element of the watt-hour meter, or to another phase.

A small transformer with taps for various voltages is placed on the potential circuit. This can be an auto-transformer, but is preferably one of the shunt type. The objection to the auto-transformer, or to omitting the transformer entirely, is, that there is more opportunity for short circuits, due to bringing the wrong side of the potential circuit into contact with the series circuit. The series auto-transformer is put in simply to economize power in testing heavy current meters. A small current in the lamp bank will give a heavy current in the series coils. This transformer is cut in or cut out by means of switches *X*, *Y* and *Z*, and is used only when the current required is more than the capacity of the lamp bank.

When switch *X* is to the left, *Y* open, and *Z* closed, the current from line *B* passes through the series coils of the meters and returns

to the line through one of the lamp banks. When X is to the right and Y and Z closed, the current from line B passes through the

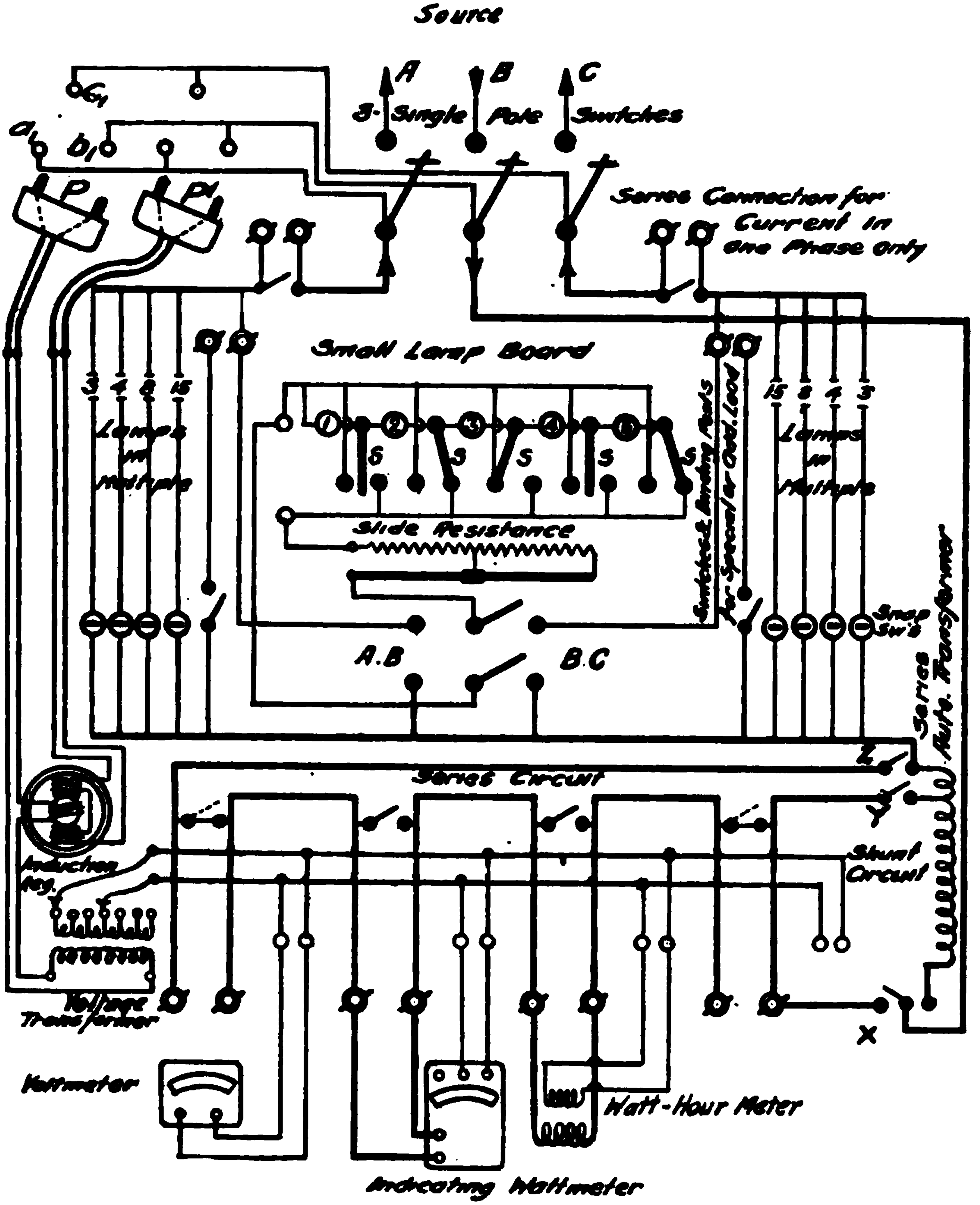


FIG. 157.—Diagram of Circuits for Use in Testing Single and Polyphase Watt-hour Meters.

coils of the series auto-transformer and to the line by way of the lamp banks. Switches Y and Z connect the current coils of the meters to one turn of the transformer winding. If there is a total

of ten turns, with 10 amperes flowing, a current of approximately 100 amperes will circulate through the turn connected to the current binding posts.

With the series current all passing through one lamp board, and the potential element plugged in on the pair of wires that supply the same lamp board, the connection is the same as on any single-phase circuit.

If the circuit is two-phase, a power-factor approximately zero can be obtained by connecting the potential circuit to the second phase, leaving the series circuit as it was. The performance of a watt-hour meter at zero power-factor is a reliable indication as to what it will do at all power-factors between that and unity. A test at zero power-factor is a simple one to make, as there is no necessity for reading voltage or current accurately, and adjustments can be made with greater facility, since the moving element does not have to be timed, the usual adjustment being to make the moving element stand still when the standard reads zero at an apparent load about equal to the full rated load.

If the load is on the side indicated by the letters *B C*, and the potential plug is connected to *b′ c′*, the power-factor is about unity. Transferring the plug to *a′ b′* gives about zero power-factor. To make the power-factor exactly zero, a little current from the same phase as the potential element can be combined with the series current *B C* to produce a resultant in quadrature with the voltage *a b*. The small lamp board is connected to the *A B* side for this purpose. If the difference in phase between the potential element voltage and series current is greater than 90 degrees, a proper adjustment of current in the small lamp board will give the required result. If less than 90 degrees, any current in the small lamp board will raise the power-factor instead of lowering it. In this event it is necessary to reverse one phase of the main circuit. This is shown graphically in Fig. 158. The same relation between potential element voltage and current in the lamp board *B C*, is shown by the lines *E* and *Ibc*. The angle of lag of *Ibc* behind *E* being more than 90 degrees, some current, *Iab*, combined with *Ibc*, will give a resultant current *I* in quadrature with *E*.

If *Ibc* is lagged less than 90 degrees behind *E*, the addition of any current in the direction of *Iab* would reduce the angle still further, thereby increasing the power-factor. To illustrate the latter point, the current *I′*, with less than 90 degrees lag, is combined with *Iab*. The projection of *E* upon the resultant current vector is greater than upon *I′*. Reversing *I′* gives it the position *I″*, in which it is readily combined with any current in the direction *Iab* to produce a resultant in quadrature with *E*.

On first glance at the diagram this looks like a change from lagging to leading current, but the adjustment is required only at zero power-factor where there is no difference between lag and lead. If there are special conditions which make it necessary to consider the direction of current, E can be reversed at the potential plug without changing Iab.

Loads at any power-factor, lagging or leading current, can be obtained by varying the proportion of lamps on the two boards.

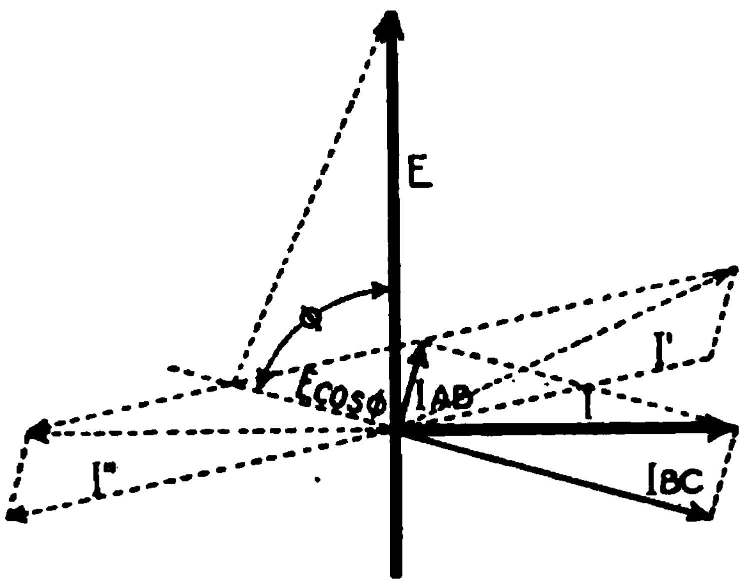


FIG. 158.

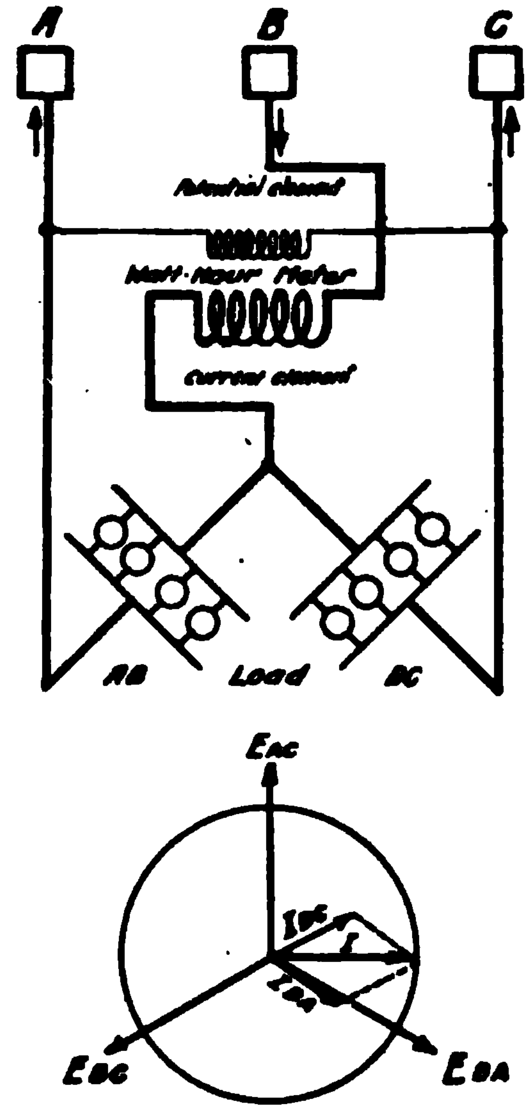


FIG. 159.—Diagram of Three-phase Circuit for Use in Testing at Various Power-factors.

Fig. 157 shows only one regulating resistance, which can be put in either phase. It should always be in the same phase as the shunt circuit, as that is where it gives the maximum regulation of true load. In adjusting this regulating resistance to keep the reading of the standard wattmeter constant as the line voltage varies, slight changes in the power-factor are introduced on account of the component in the other phase not being changed in the same proportion at the same time. It is not worth while to attempt to regulate both phases, as there is no object in measuring the power-factor with the degree of accuracy required in measuring true load.

With a three-phase circuit, the various power-factors are obtained in a similar way. For zero power-factor the load is about equally divided between the two lamp banks and the potential element current is supplied from the outside lines.

Fig. 159 shows this connection. *Eac*, *Ebc* and *Eba* represent the phase relations of the voltages. *Ibc* and *Iba* are the current vectors for the lamp boards *B C* and *B A* respectively. Their resultant, *I*,

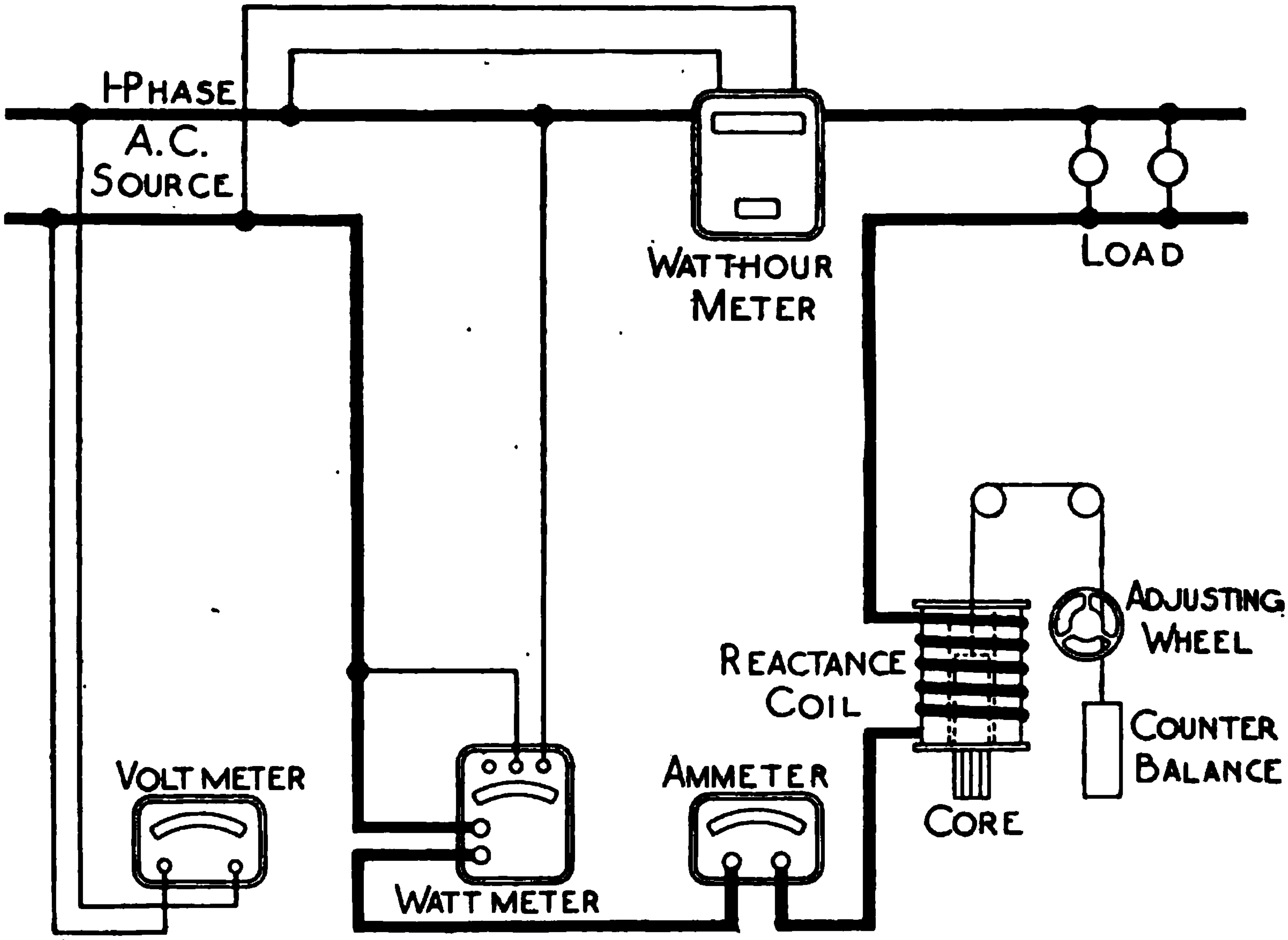


FIG. 160.—Diagram of Circuit for Use in Testing at Various Power-factors Obtained with Reactance Coil.

will be in quadrature with *Eac* when they are about equal. By increasing one and decreasing the other, the direction of *I* can be changed to take any position between them, the total angle being about 60 degrees. This corresponds to a range of power-factor from zero to 0.5 both ways, or from 60 degrees lead when the load is all on *B A*, to 60 degrees lag when the load is all on *B C*. For power-factors above 0.5 the potential element is plugged on *Ebc*, or *Eac*. Under the conditions of series current shown in Fig. 159, such a change in phase of potential element voltage would change the power-factor from zero to

about 0.866. If the load is all on one lamp board, and the potential elements are fed from the same phase as the other lamp board, the power-factor is again 0.5, but any combination of currents from the two phases gives a higher power-factor. For example, the potential elements may be plugged on *Ebc*, while the current is all on the lamp board *B A*. The angle of lag is 60 degrees or the power-factor is 0.5. Gradually shifting the load from *B A* to *B C* changes the power-factor through successive steps until, when it is all on *B C*, the power-factor is unity.

The use of the induction regulator in adjusting the phase relation of the potential element and series currents affords a means of quickly making comparatively small adjustments in phase and voltage of the potential element circuit.

The binding posts for connections in parallel with the lamp boards are convenient when the load has to be increased beyond that which can be obtained with the lamps, and also for putting in any special load. As the two lamp boards have a permanent connection on one side, a single wire connected between the opposite sides puts them in parallel. All of the lamps in both lamp boards are then available for single-phase tests, but the outside switches must not both be closed at the same time.

The small lamp board illustrated in Fig. 157 affords a ready means of regulating a large current by controlling a small fraction thereof. 1, 2, 3, 4 and 5 are 16 c-p. lamps, and *S*, *S*, *S*, *S*, *S*, two-point switches. If *S5* is to the right, and all the others open, the five lamps are in series. By proper manipulation, any series, parallel or multiple series combination may be obtained. As shown in the figure, 1 and 2 are in series, 3 is across the line, and 4 and 5 are in series in multiple with 1 and 2.

Various other methods of obtaining conditions under which watt-hour meters may be tested for accuracy on inductive loads are available, the best known of these being the **reactance-coil method,** the **two-generator method,** the **two-transformer method,** the **two-phase resistance method,** and the **three-phase method,** all of which are illustrated and described as follows:

In the method commonly used to obtain the desired power-factor, a coil with variable reactance is connected in series with the load or translating device, as shown in Fig. 160 and Chapter VI.

The power-factor of the circuit is varied by adjusting the laminated-iron core in the coil by means of the adjusting wheel.

A serious objection to this method is that the power-factor changes when the load is altered, making it necessary to readjust the core continually in order to obtain the same power-factor for each of the loads desired.

The power-factor of a circuit may be calculated from the indications of a reliable ammeter, a voltmeter and an indicating wattmeter.

An ammeter, and the current coils of an indicating wattmeter, are connected in series with the load or translating device, and the potential coils of the wattmeter and voltmeter are connected across the source of current.

The product of the values of current and voltage in an inductive circuit gives the apparent power in watts. The indicating wattmeter

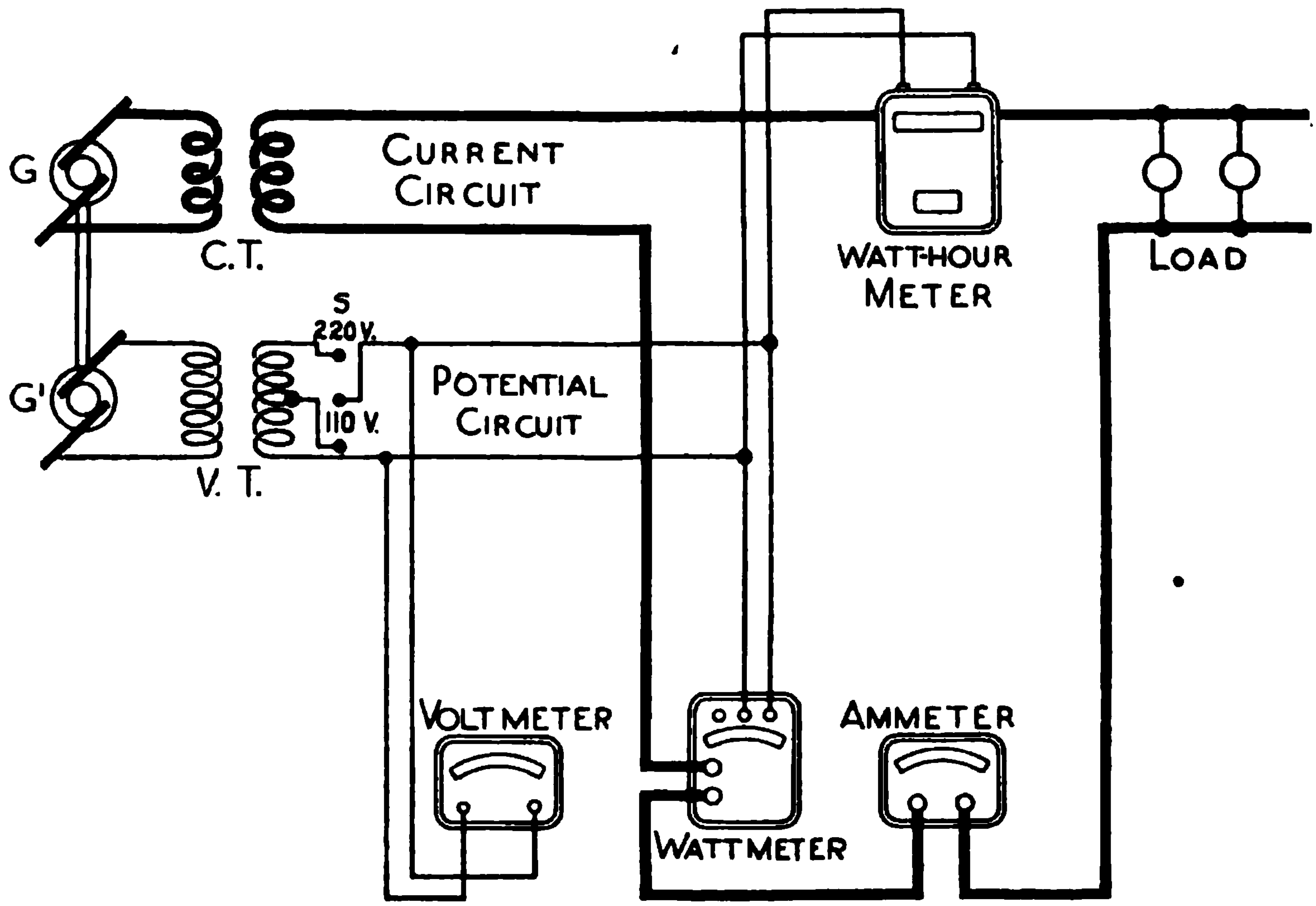


FIG. 161.—Diagram of Circuits for Use in Testing at Various Power-factors Obtained with Motor Generator Set.

shows the true power in watts, and the ratio of the true watts to the apparent watts is the power-factor of the circuit, i. e.:

$$\text{Power-Factor} = \frac{\text{True Power}}{\text{Apparent Power}}$$

Some laboratories use a specially designed generator set, which consists of two alternators coupled together and driven by the same motor.

As shown in Fig. 161, one alternator, *G'*, is used for potential purposes, supplying only a limited amount of current at standard voltage.

One of the alternators is so arranged that its stator, which may be either the armature or field, can be shifted around the shaft with respect to the stator of the other alternator.

When both stators are in their normal positions, the currents of the two alternators will be in phase with each other.

The frequency of both alternators will always be the same, as the two rotors are rigidly coupled together.

The stator of one alternator being so arranged that it may be

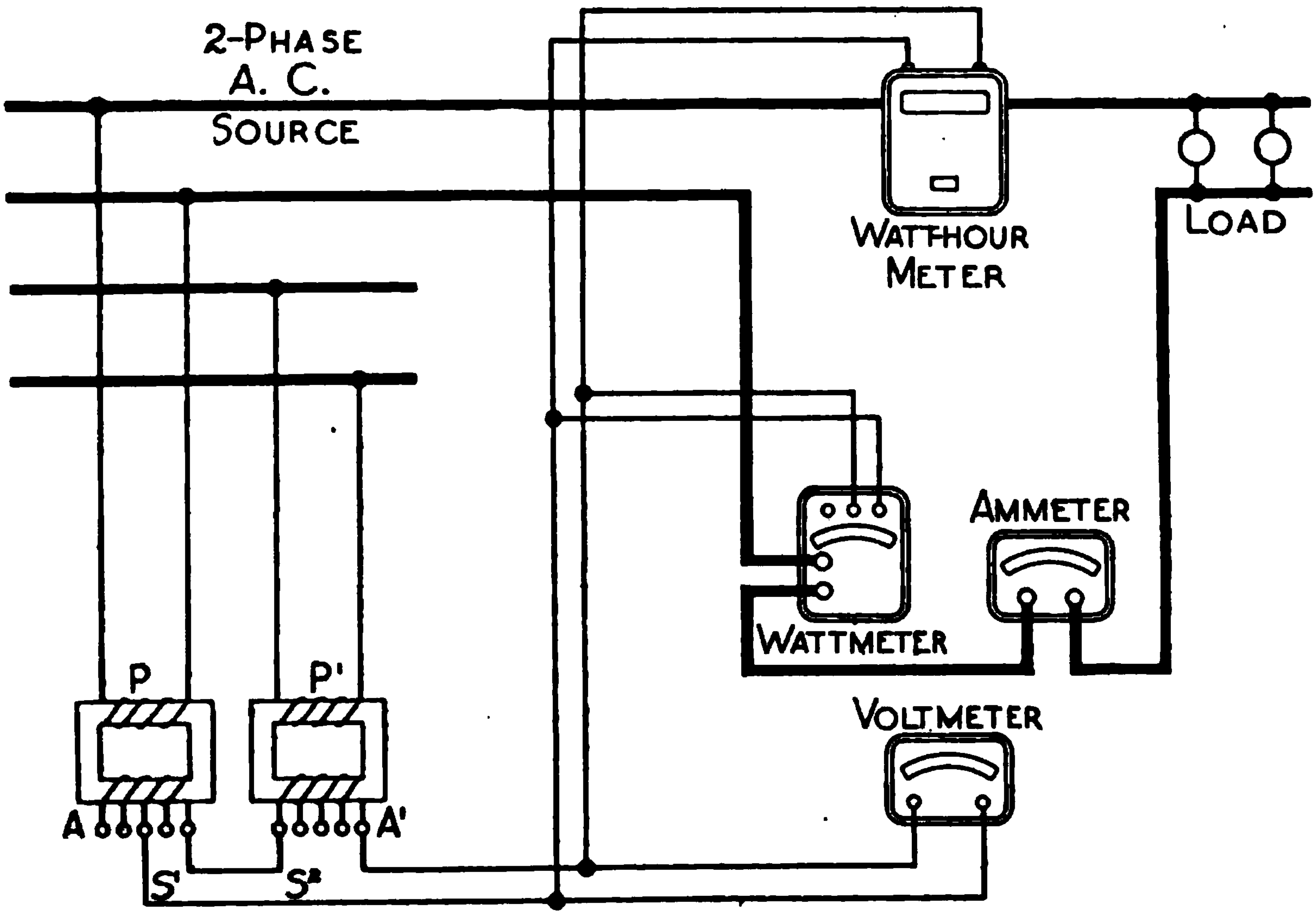


FIG. 162.—Diagram of Two-phase Circuits for Use in Testing at Various Power-factors Obtained with Special Voltage Transformers.

shifted, any desired phase relation can be obtained between the currents of the two machines.

Rheostats in circuit with the fields may be used to make the apparatus more flexible.

It is evident that, if the current or load circuit of a wattmeter is connected to one alternator, and its potential circuit connected to the other alternator, any desired power-factor may be obtained by adjusting the movable stator.

A scale may be made and placed in such a manner that the stator-shifting device will indicate the angle of phase relation between the

currents of the two alternators, or the power-factor, without either being measured. The wattmeter only would then be necessary—the voltmeter and ammeter being used only for initial calibration of the power-factor scale.

For testing single-phase watt-hour meters on inductive loads, power-

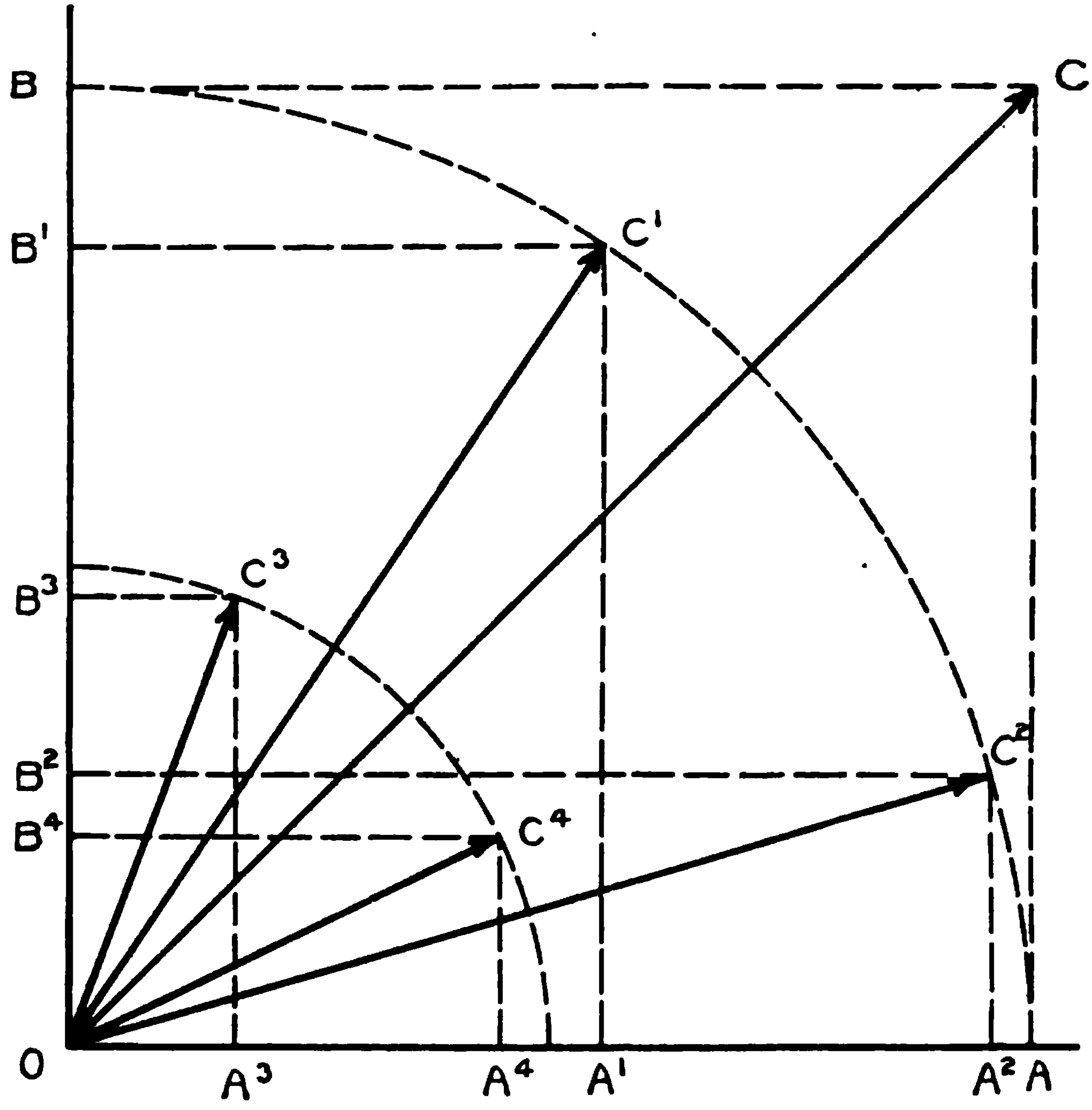


FIG. 163.—Vector Diagram of Relation of Voltages in Circuits Shown in Fig. 162.

factors adequate to meet ordinary requirements may be obtained from the circuits of a two-phase system in the following manner:

One phase is used for the current circuit of the meter under test, and should have a non-inductive load; therefore the current and voltage are in phase with each other.

The potential applied to the watt-hour meter is taken from the low-tension winding of two special voltage transformers, the high-tension windings of which are connected to different phases and their low-tension windings connected in series.

When the transformers *P1* and *P2*, Fig. 162, are thus connected,

a voltage may be obtained from their low-tension winding, which is a resultant voltage, having a phase displacement with respect to the voltage of the current circuit. Therefore, the load current will lag sufficiently behind the voltage applied to the meter to produce the same condition that exists on a single-phase circuit with an inductive load. With this method the load can be varied, and the phase displacement between the current and voltage applied to the watt-hour meter will remain the same.

If it is desirable to obtain several different power-factors, using the same voltage transformers, it is evident that the transformers must have suitable taps to their low-tension windings, in order to give the required voltages, so that, when the low-tension windings are connected in series, a resultant voltage may be obtained that will have a value equal to the rated voltage of the meter under test, with the proper phase displacement.

The action of the transformer may be shown very plainly by a graphical construction based upon the parallelogram of forces.

In Fig. 163, the horizontal line OA represents the full voltage of transformer P. This voltage is in phase with the load current. OB represents the full voltage of transformer P^1, which is 90 degrees ahead of the voltage of P, and equal in magnitude. The resultant voltage obtained from the two transformers connected in series is represented by OC, which has a lead of the angle ϕ ahead of OA, and a greater length than desired. Now, if the values of $OA1$ and $OB1$ had been selected (by means of suitable taps to the secondary winding of the transformers), then the resultant of $OA1$ and $OB1$ would be $OC1$, leading by the much greater angle ϕ, and having the proper length.

If the values of $OA2$ and $OB2$ had been selected instead, the resultant of these would have been $OC2$, leading by a much smaller angle than in either of the previous cases. By halving the values OA and OB, the system would be adapted by a meter built for half the voltage given above. The resultants are shown by $OC3$, and so on. Thus by selecting the proper values of voltage from each phase, a resultant voltage may be obtained which will have any desired magnitude and phase relation.

The transformer taps may be brought to a circular switch, the position of which will indicate the voltage and power-factor under which condition the voltmeter and ammeter will be unnecessary.

A double-throw switch, to give non-inductive load, should be connected in the potential circuit, so that the potential to the meter may be connected to the same phase as the current circuit.

The same principles may be applied to any polyphase system, and will be found very useful, especiallly for laboratory and shop testing.

Another method is similar to the transformer method except that two non-inductive resistances with adjustable contacts are connected across two phases, as shown in Fig. 164.

The resistances *R1* and *R2* are suitable to withstand line voltage and have a current capacity of 1 or 2 amperes.

The adjustable contacts have terminals to which are connected the potential leads of the watt-hour meter under test.

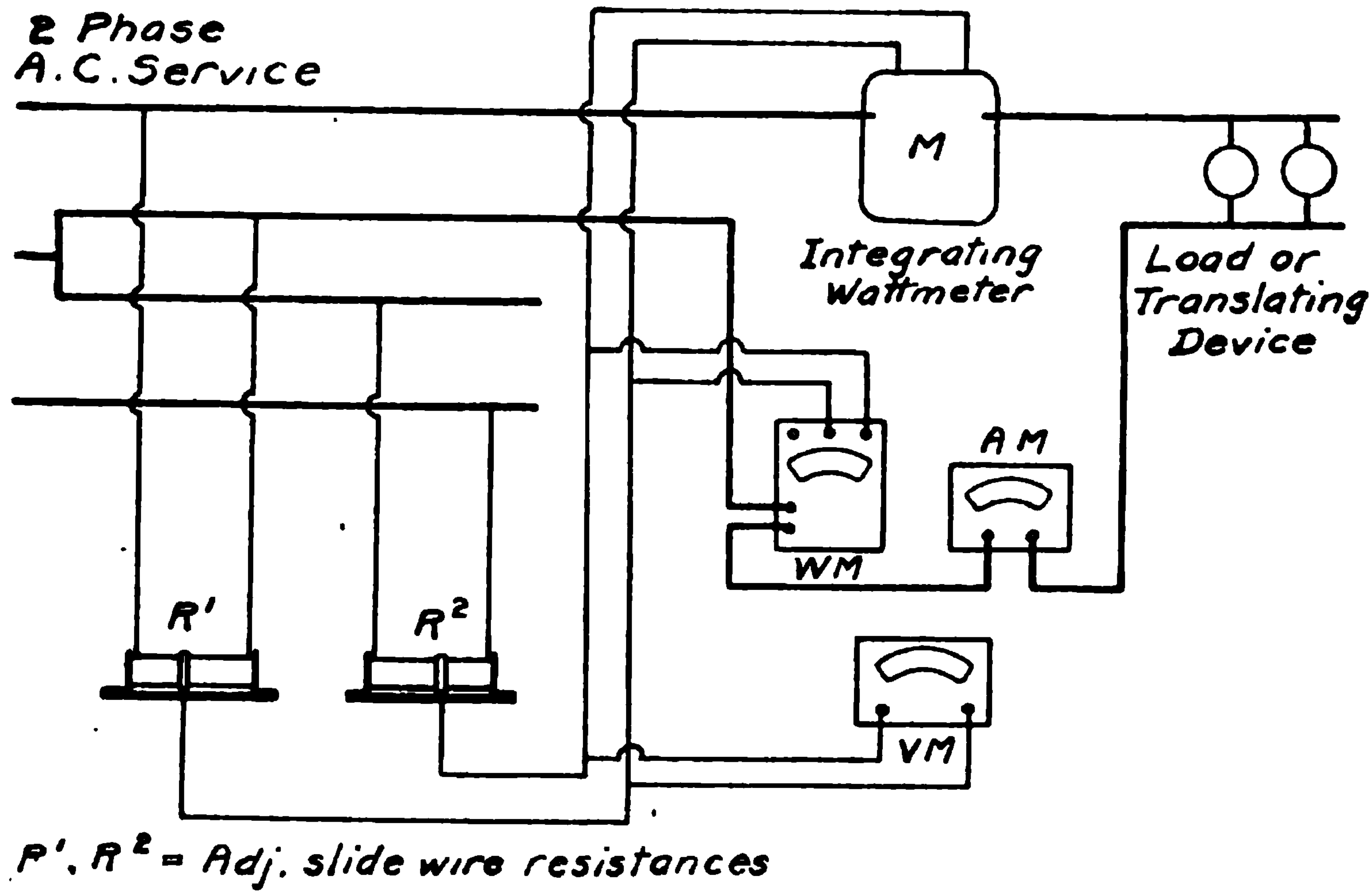


FIG. 164.—Diagram of Two-phase Circuit for Use in Testing at Various Power-factors Obtained with Two Non-inductive Resistances.

A non-inductive load is applied to the current circuit of the watt-hour meter in the same manner as in the transformer method.

It is evident that, with this arrangement, a drop of potential with any desired phase relation with respect to the load current may be obtained by changing the position of the adjustable contacts on the resistances.

When the proper contact points have been determined, the position of the adjustable slides may be so marked that approximately the same power-factor can be reproduced without the voltmeter and ammeter. A double throw potential switch should be provided and connected to the current and to the resultant voltage circuit, so

that the voltage supplied to the meter can be taken from either circuit as desired. The voltage, to produce the inductive load condition or the normal line voltage, may then be conveniently and readily obtained as desired.

The apparatus for this method can be built in small portable form, which is adapted for testing meters in service, at any installation wheer a polyphase circuit is available.

When testing single-phase watt-hour meters, where a three-phase

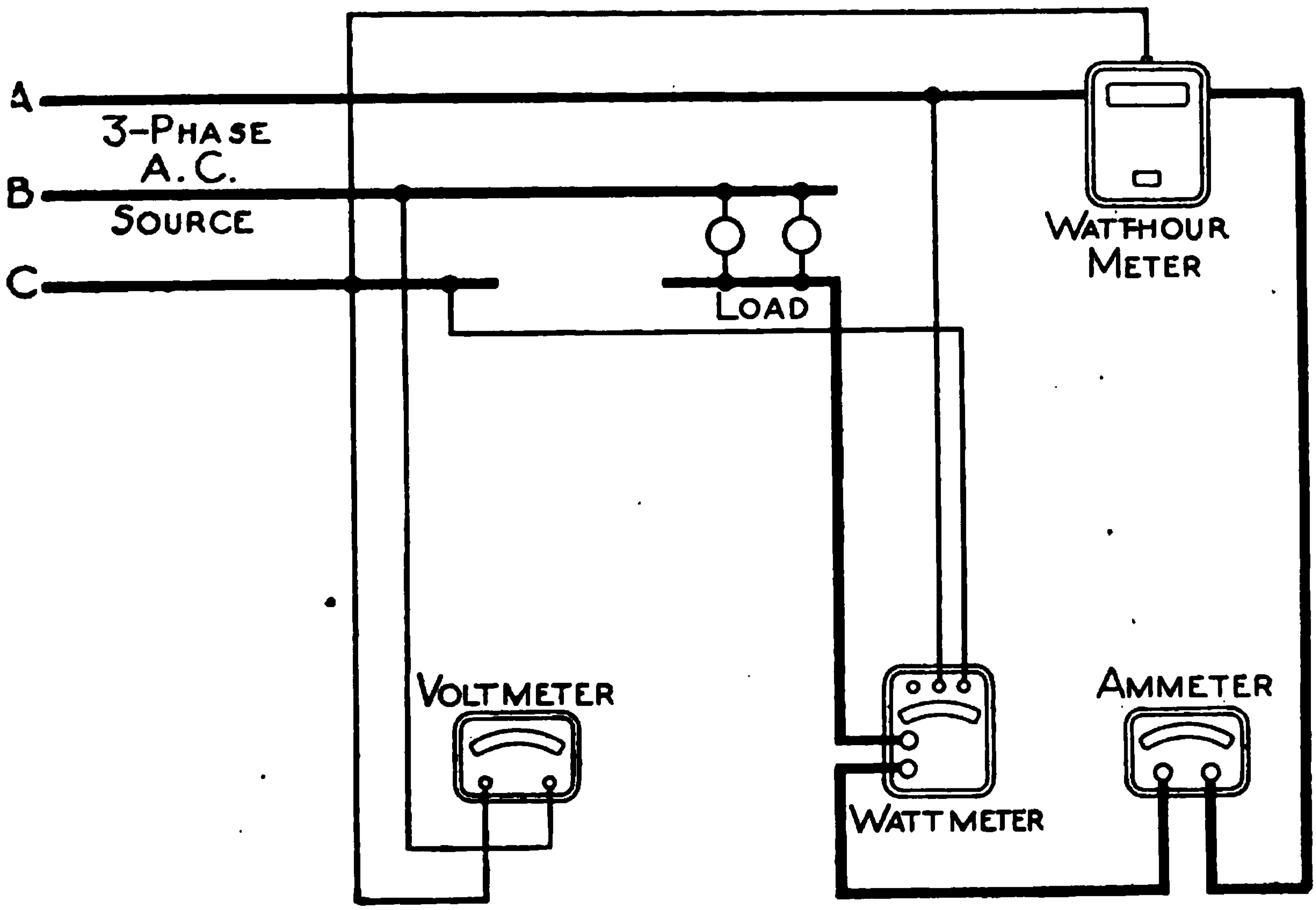


FIG. 165.—Diagram of Three-phase Circuit for Use in Testing at 0.50 Power-factor.

circuit is available, the effect of a load with a 50 per cent power-factor is readily obtained by the connections shown in Fig. 165.

First, a single phase circuit is taken from any two wires and a regular test on non-inductive load is made. The current circuit passes through the watt-hour meter, wattmeter and load, in the order named. When the meter is adjusted properly, the potential lead is removed from the regular point to which it is connected and, with the corresponding wattmeter lead, is connected to the third wire.

On account of the 120-degree relation between the phases this gives the effect on the meter of a current with a power-factor of 50 per cent.

To ascertain if the current is leading or lagging, a small impedance coil should be connected in series in the indicating instrument potential circuit. If the indication of the instrument increases, the current is lagging; if it decreases, the current is leading. and the load should be connected across the *A* and *C* wires, and the potential leads connected to the *B* wire.

The voltmeter and ammeter are unnecessary in the actual test.

The Selection of Laboratory Instruments.

It has been demonstrated that the **primary standards** are, by their nature, **adapted for continuous current measurement only;** and that the potentiometer is the instrument most capable of measuring electromotive force, current and resistance, in terms of these standards.

Potentiometer.

In the potentiometer, the fall of potential across a series of standardized resistances is balanced against the electromotive force of a standard cell; the balance being determined by means of a galvanometer connected in series with the potential being measured. Current for the resistances is provided by means of an auxiliary storage battery, and is controlled by a rheostat.

In **the measurement of potential differences,** an unknown and a standard are successively balanced; and, provided only that the current in the instrument remains the same for the two operations, the unknown potential difference is given in terms of the standard by the ratio of the potentiometer settings.

The accuracy of measurement depends chiefly upon the relative accuracy of the potentiometer resistances, the accuracy of the cell used as standard, and the sensitiveness of the galvanometer employed to indicate a balance. These three requirements are so well met in practice that with a potentiometer whose calibration is carefully and frequently checked, an accuracy of 0.01 per cent is easily attainable.

Besides its accuracy, the potentiometer has the advantage of convenience. **The resistances** are divided into groups, or decades, of equal steps. The potential drop in one step of a decade equals that in ten steps of the next lower decade. The successive readings of the dials indicating these steps thus give the digits of the setting. A slide wire may take the place of several of the dials. It is only necessary to adjust the current to such a value that the standard cell is balanced across a portion of the resistance indicating its electromotive force, when the

readings of the instrument will give the potential differences subsequently measured, without calculation In addition to the direct measurement of voltage, the potentiometer furnishes a means for the precise measurement of current and of resistance when used in connection with resistance standards. By using resistance standards of decimal values the advantages of direct reading are retained for current measurements, only the insertion of the decimal point having to be considered. For flexibility, accuracy and convenience, the potentiometer is thus seen to be an admirable instrument for the measurement of the three fundamental electrical

FIG. 166.—Potentiometer, Slide Wire Type, Leeds and Northrup.

quantities. By combining measurements of two of these quantities we have also a measure of power.

The numerous types differ in the method of dividing the potential drop into decimal steps. One of the simplest forms is a series of equal coils with a slide wire having decimal subdivisions and a resistance equal to one coil. A switch makes contact with the terminal of any one of the series coils, and there is also means for making contact at any point of the wire. Practical considerations of construction limit the values of the resistances that may be employed when the series slide wire is used, to 20 to 100 ohms per volt on the normal range The Crompton and the Leeds & Northrup Type K potentiometers are of this form (Fig. 166).

When high resistances, of the order of 10,000 ohms per volt, are employed, various methods are used to make the potentiometer set-

tings. In one type there are several dials of equal coils in series, whose steps are multiples of 10. The terminals to which the unknown potential difference is applied connect to the switches of the two end dials. Changing the resistance on the intermediate dials varies the drop between these terminals, the current being maintained constant by simultaneously changing the resistance in the battery circuit a corresponding amount. This double operation is effected by the use of double dials. The Otto Wolff potentiometer is of this type (Figs. 167 and 168). In another type the steps of the main dial are subdivided by means of a second series of coils, which can be moved so as to shunt any one, or, in some types,

FIG. 167.—Potentiometer, Dial Type, New Model. Wolff.

any group of two or more of the steps of the main dial. Examples of this type are the Siemens & Halske and the Leeds & Northrup Standard potentiometers. A recently developed type combines the potentiometer with the deflection principle (Fig. 172). The greater part of the unknown potential difference is balanced in the ordinary manner, and the small unbalanced remainder is indicated on a deflection instrument. This method has the advantage of speed, and an accuracy of 0.02 per cent is attainable.

The types of potentiometer differ, also, in the method of **balancing the standard cell.** It may be introduced at the same points as the unknown potential differences, or special connections may be provided for it. The latter arrangement is the more convenient as it is unneces-

sary to disturb the setting of the instrument. This is of importance, for the constancy of the current is the fundamental assumption of the potentiometer, and should be frequently checked. Usually a single pair of tap-in points for the standard cell is not sufficient. Preferably the resistance across which the cell is balanced should be variable, inasmuch as the cells, used as standard, do not all have the same electromotive force, and further, because their variation with temperature may have to be considered.

The range of the ordinary potentiometer is 1.5 to 1.8 volts, 0.1 volt for each step of the first or main dial. The setting is usually read-

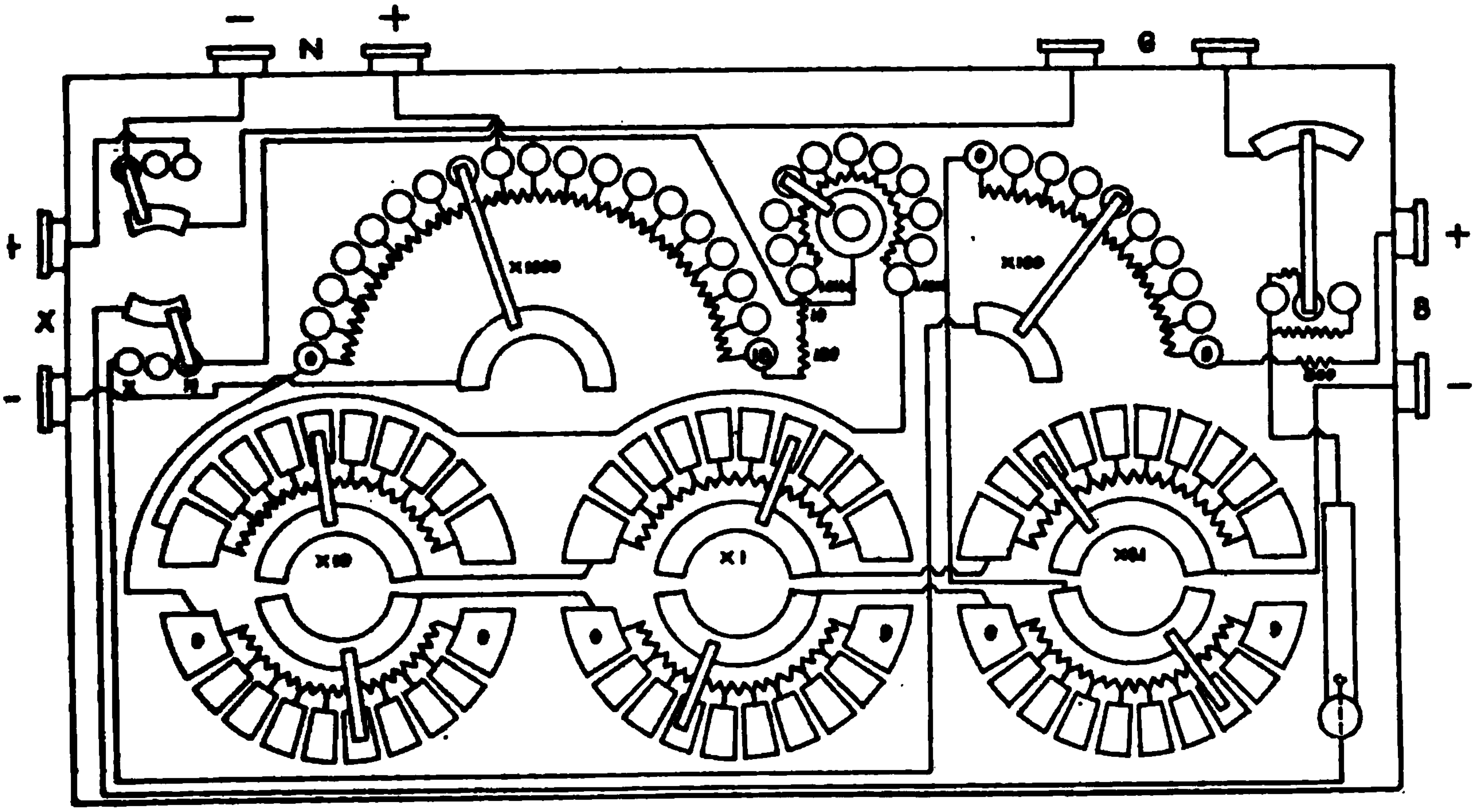


FIG. 168.—Diagram of Potentiometer Connections. The Battery at B, Galvanometer at G, Standard Cell at N, Unknown Quantity at X. The Five Dials have Steps of 1000, 100, 10, 1 and .1 ohm Respectively.. New Model. Wolff.

able directly to 0.00001 volt. For measuring very small potential differences the range of some potentiometers may be reduced. The reduction is usually to 0.1 or 0.01 of the normal range, and is accomplished by inserting series resistance or a combination of shunt and series resistance with the main circuit. The percentage precision of reading is thereby increased inversely as the reducton factor, unless limited by galvanometer sensibility. Special potentiometers for the measurement of low potential differences are also constructed, which are designed for the prevention of errors due to thermal electromotive forces and variable contact resistances in the potentiometer circuit. Such an instrument should be of low resistance to secure the highest sensibility.

When a potentiometer is used to measure higher voltages than 1.5 volts, a "multiplier," or **volt box** is ordinarily used. A volt box is a series resistance coils, to the terminals of which is connected the unknown voltage and across a known fraction of which the drop is measured. The ratio of the total resistance to this fraction is the multiplying factor of the box. The construction is generally such as to give two or more factors.

Fig. 169 illustrates the connections of the potentiometer manufactured by the Leeds & Northrup Company, shown in Fig. 166.

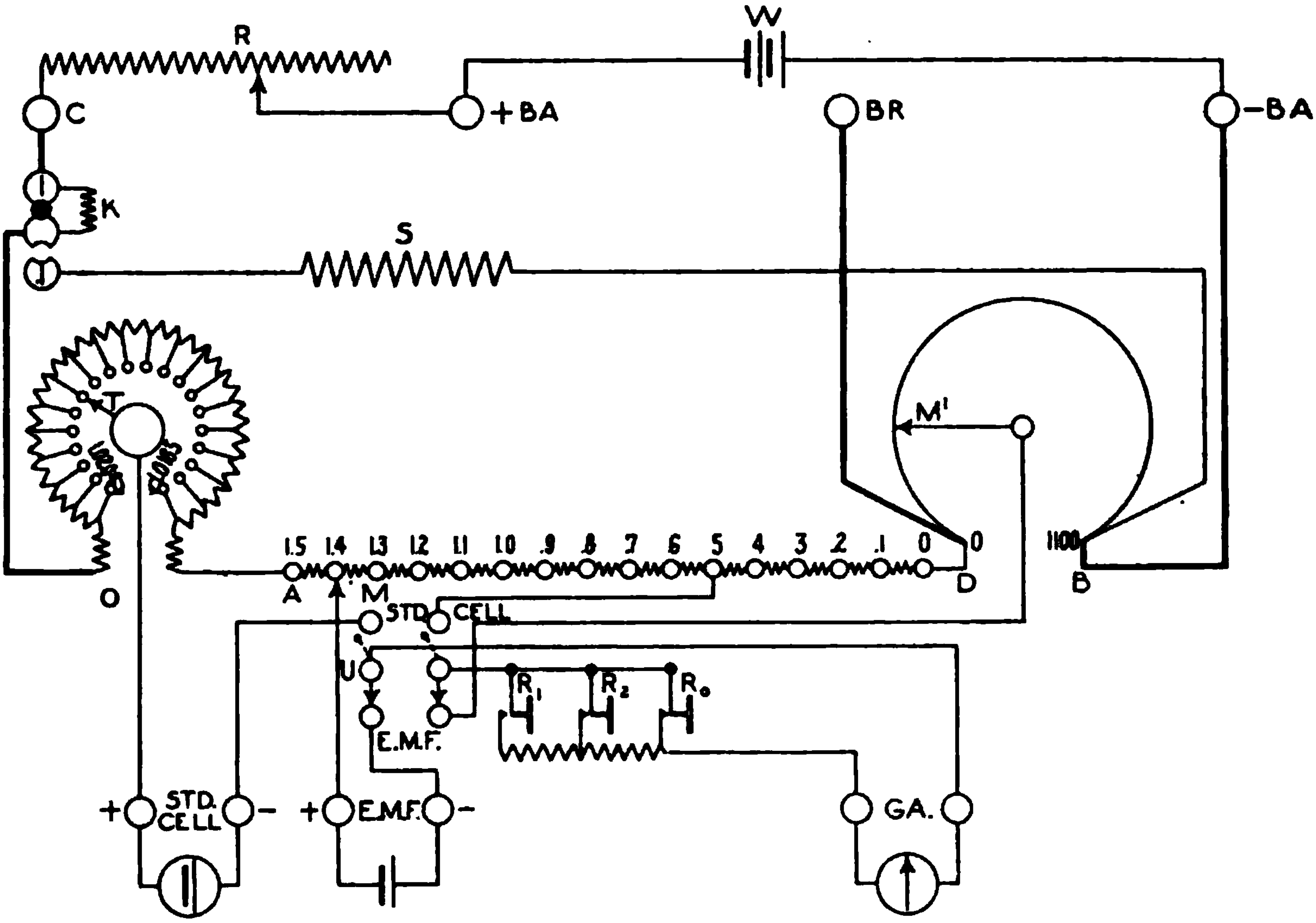


FIG. 169.—Diagram of Potentiometer Connections. Tpye K, Leeds & Northrup.

The essential part of the instrument consists of fifteen 5 ohm coils, *AD,* wound on metal spools, and adjusted to a high degree of accuracy. These coils are connected in series, and have in series with them an extended wire *DB,* the resistance of which is 5.5 ohms. A scale in connection with the wire *DB* is divided into 1,100 equal parts. A contact, *M,* is arranged so that it can make contact at any point on the extended wire *DB.* Current from the battery *W* flows through these resistances, and, by means of the regulating rheostat *R,* it is adjusted so as to be exactly one-fiftieth of an ampere. Since the resistance of each coil is five ohms, and that of the extended wire 5.5 ohms, and the current flowing therein is one-fiftieth of an am-

pere, the potential drop across each coil is 0.1 of a volt, and that across the extended wire *DB* is 0.11 of a volt. By placing the contact point *M* at zero, and moving the contact *M,* the electromotive force between *M* and *M'* may be varied by steps of 0.1 of a volt from 0 to 1.5 volts. By moving the contact *M'* from 0 to 1,100, the electromotive force between *M* and *M'* may be varied by infinitely small fractions of a volt, and the values thereof read directly on the scale. To make use of this variable electromotive force in making measurements, an unknown electromotive force is introduced in series with a galvanometer between the points *M* and *M'*, and, in opposition to the fall of potential along *AB*. The contact points *M* and *M'* are then adjusted until the galvanometer shows that no current is flowing, when the value of the unknown electromotive force can be read from the position of the points *M* and *M'*.

In the diagram the connections show the unknown electromotive force introduced at the binding posts marked e. m. f., and the galvanometer at the point *Ga.* In series with these are three keys, *R1*, *R2* and *Ro.* When the key *R1* is depressed, it closes the circuit through a high resistance. *R2* closes the circuit through a lower resistance, and *Ro* through no resistance. The purpose of *R1* and *R2* is to protect the galvanometer against excessive deflections when the opposing electromotive forces are not approximately balanced.

At the point 5, on the series of resistances *AD,* a wire is permanently attached which leads to one point of the double throw switch *U*. Between *A* and *O* there is a series of 19 resistances with a sliding contact *T*. The resistance between .5 and *A* is exactly that which corresponds with the electromotive force of one volt, and that between *A* and 1.0185 is a sufficient addition to make the resistance, between .5 and this point, correspond to an electromotive force of 1.0185 volts. Between this and the end of the series of resistances there are 19 coils, which increase the corresponding electromotive force by steps of .0001 to 1.024 volts. This range corresponds with the variation in the range of the Weston cadmium cell. The circuits are so arranged that the two points *T* and 5 may be thrown in series with the galvanometer and the keys *R1*, *R2* and *Ro.* In this circuit are also the binding posts marked "standard cell," to which the standard cell is to be connected. To adjust the current to one-fiftieth of an ampere, the double throw switch *U* should be placed in the position indicated by the dotted lines. The point *T* should be set to correspond with the electromotive force of the standard cell, and the rheostat *R* regulated until the galvanometer shows no deflection when the keys *R1*, *R2* and *Ro* are depressed. The unknown

electromotive force may then be measured by throwing the double pole switch, *U*, to the position indicated by the full lines, and adjusting the points *M* and *M'* until the galvanometer shows no deflection when the keys are depressed. After a balance has been obtained, the current in the potentiometer coils may be checked by changing the position of *U* and touching the contact key *Ro*. A galvanometer balance shows that no change has occurred. A slight deflection calls for a slight readjustment of *R* and a corresponding readjustment of *M'*.

The resistance *S* is of such value that when it shunts the wire *OB*,

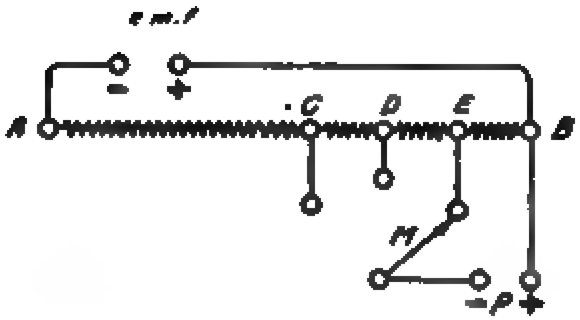


FIG. 170.—Diagram Illustrating Connections of Volt Box.

FIG. 171.—Volt Box. New Model. Wolff.

the total resistance between *OB* is one-tenth of the same unshunted. When the shunt is applied, the fall of the potential between any two points on *AB* will be exactly one-tenth of its previous value. The low scale is applied by moving the plug from position 1 to the position 0.1. The resistance *K* is of such value that it compensates for the reduction in resistance caused by plugging in the shunt coil *S*. With this change the potentiometer reads from 0.16 volts down by indicated steps of 0.000005 of a volt. The regulating rheostat *R* is mounted in the potentiometer case.

Fig. 170 illustrates the connections of the usual form of volt box.

A B is a high resistance of which *C B* is one-tenth, *D B* one-hundredth,

and *E B* one-thousandth of the total resistance. The potentiometer reading is accordingly multiplied by ten, one hundred, or one thousand, depending upon whether the switch *M* is set on *C, D,* or *E.* In using a volt box it is necessary to connect the unknown *EMF* at the posts so marked and the potentiometer to the posts marked *P.* The potentiometer reading is multiplied by a factor depending upon the position of the switch *M,* which factor is indicated on the box. In making these connections, care should be taken not to connect the potentiometer to the posts marked e. m. f.

Any resistance of known value may be used in connection with the potentiometer for the measurment of voltages in excess of its capacity; it is best, however, to provide a volt box which has been especially designed for this purpose. The potentiometer is afforded the best protection against damage from high voltage by using volt boxes in which there are sufficient coils to reduce the dielectric stress per coil to a safe value (Fig. 171).

In the design of volt boxes the need of specially good insulation must be regarded; and great care is necessary in use to prevent the high voltage under measurement from leaking to the potentiometer. The terminals of the volt box must be well separated and well insulated. The resistance should be divided into a number of coils in series, both for insulation and for dissipation of heat. The lower the resistance used the greater will be the heat developed. However, a high resistance reduces the sensibility, and is moreover less constant. The use of wooden spools and the winding of more than one layer on a spool are alike prejudicial to heat dissipation and to constancy of resistance. The resistance used should be between 100 and 300 ohms per volt.

The capacity of the volt box depends upon the maximum potential to be measured. When voltmeters having double or triple scales are to be tested, accurate results may be obtained by calibrating the low range with the potentiometer, and determining the values for the higher ranges by calculation from the ratio of the resistances of the instrument circuits. The disadvantage of this method is that the resistance of the instrument being tested is not subjected to the same stress in testing as in service; and defective insulation may cause leakage under service conditions which would tend to lower the resistance of the instrument. A test on the lower range only would not develop this fault, therefore it is best to provide a volt box, the capacity of which is suitable for the highest range of the voltmeters tested therewith.

For a central station laboratory it is best to **provide a potentiometer** of low internal resistance.

The chief advantage of the low resistance is in sensibility, which in-

creases as the resistance is reduced. In the low resistance instrument, the effect of poor insulation and possible leakage between parts is less important than in the case of high resistance. The change of the resistances with time and their variation with atmosphere humidity are also less in the case of low resistance. The low resistance potentiometer has, however, the disadvantage of using a larger current, which is somewhat more difficult to maintain constant. The slide wire types often have additional minor difficulties, which can, however, be overcome by proper construction. For the determination of the fall of potential across low resistances, such a type is especially advantageous, as it permits the use of shunts which will carry their full load current without artificial cooling, such as water circulation, oil baths, etc. Potentiometers with the regulating rheostats built in the case are very convenient, not only in portable work, but in the standardizing laboratory as well, since such an arrangement permits of more rapid manipulation.

The type selected should be one in which it is unnecessary to set the dials to a fixed position in order to obtain a comparison of the working and standard cells. The necessity for so setting the dials is a source of inaccuracy and inconvenience, especially where the current from the working cell is unsteady. The facilities which the design affords for the interchecking of the various coils is a matter worthy of consideration. It is desirable that the contact blocks and switches be provided with sufficient clearance to permit thorough cleaning, and that the insulation of these parts be sufficient to minimize the effect of surface leakage.

The potentiometer is not usually considered as **a portable instrument,** though, when fitted with a sensitive low resistance galvanometer of the pivoted movable coil type, it can be transported from place to place and used wherever desirable. In the laboratory the best results are obtained when the potentiometer and its accessories are set up in a fixed permanent position and used in connection with a reflecting galvanometer. The location of the galvanometer should be such that it is not subject to vibration; the best arrangement being to place it on a shelf attached to a solid wall. It is best to install permanent leads for connecting the galvanometer, auxiliary battery, and standard resistances. The resistance of the leads connecting the galvanometer and standard resistances with the potentiometer do not affect the accuracy of any measurement, since the potentiometer principle is a null one, and when a balance is obtained, no current is flowing.

Poor insulation of the auxiliary and working batteries is **a frequent source of error** when measuring by the potentiometer method, on account of leakage which results in the galvanometer being deflected by

FIG. 171.—Potentiometer. Brooks Deflection Type, Leeds & Northrup.

current which the potentiometer is not intended to measure. The best method of protecting the potentiometer and its appliances against leakage is to provide for the insulating of the auxiliary battery, potentiometer, volt box, and galvanometer, by means of hard rubber or glass blocks which present a long path of narrow cross section for surface leakage, and to place between these blocks and the ground, metallic conductors in the form of tinfoil, or thin copper sheets. These should all be connected together by means of a small wire and permanently grounded. The surface of the potentiometer should be frequently cleaned by means of soft dry cloth; the latter should be forced down between the contact blocks so as to remove any dust which may have accumulated.

FIG. 173.—Standardising Set, Portable Potentiometer Type, Siemens & Halske.

The type of instrument designed by Dr. Brooks of the National Bureau of Standards, affords a **ready means of calibrating voltmeters and ammeters.** This device is called a deflection potentiometer, and is manufactured by The Leeds & Northrup Company (Fig. 172).

In operation, the major portion of the current or voltage is measured by the null principle—the value being determined by the position of a dial switch on its contact blocks. The remaining portion of the result is read on the calibrated scale of a pivoted, movable coil galvanometer resembling an ordinary voltmeter. The accuracy of the results obtained can be checked against the standard cell which is made a portion of the equipment These potentiometers may be used on commercially steady circuits, as the changes in current or voltage are quickly followed by the index of the galvanometer which is designed to be just aperiodic, taking up a new position without oscillation. For testing voltmeters, these instruments are accurate and rapid. For current measurements, specially

constructed resistances having approximately 6 volts drop must be supplied—the number depending upon the capacity desired.

Another type of instrument for central station use is known as the Siemens & Halske standardizing set, supplied by James G. Biddle of Philadelphia (Fig. 173). This instrument is called a standardizing set from the fact that it is a combined ammeter and voltmeter, which can be checked directly against a standard cell, located within the

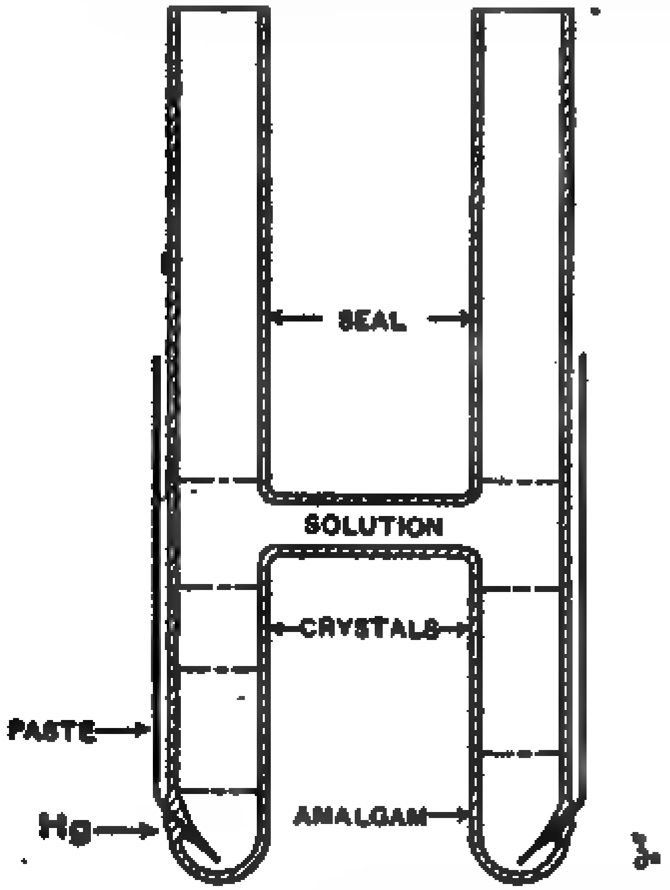


FIG. 174.—Types of Standard Cells.

same case, by a simple manipulation of suitable switches. This type of instrument is well adapted for checking portable indicating instruments to a degree of accuracy usually sufficient for commercial purposes, but it is not suitable in cases where highly refined results are required. For current measurements, specially constructed resistances suitable to the capacities desired must be supplied. These instruments—the deflection potentiometer and standardizing set—provide for the small central station, a simple form of primary standard for the checking of portable instruments, etc., and for larger central stations a portable indicating instrument, or secondary standard, which can be checked in position wherever it might happen to be; a feature which is valuable in

case it is desired to test switchboard meters in position where stray fields of constant intensity exist.

The standard cell should be of the unsaturated Weston type, as this form is superior to any other by reason of its high accuracy, constancy, and negligible temperature coefficient. The electrodes of this cell consist of cadmium-amalgam, covered with a layer of cadmium-sulphate crystals; and pure mercury in contact with a paste of mercurous sulphate, cadmium-sulphate, cadmium-sulphate crystals, and metallic mercury. The electrolyte is an aqueous solution of cadmium sulphate and mercurous sulphate

FIG. 175.—Galvanometer, D'Arsonval Wall Type, Leeds & Northrup.

The electromotive force of this cell is about 1.0185 volts. (See Circular No. 29, Bureau of Standards.) (Fig. 174.)

As a check against using cells which have been damaged by improper use, it is important that at least two, and preferably three cells be provided: in the latter case, two should be set aside for reference standards, and the third used as a working cell. If two cells fail to agree with the third, the latter should be sent to a standardizing laboratory for test.

A galvanometer is an instrument used for detecting and measuring the magnitude and direction of small electric currents. In the D'Arsonval type the movable element is in the form of a coil, arranged to swing freely in the field of a permanent magnet (Fig. 175, see Chapter II). The

coil may be supported in the magnet field by means of a single ribbon or a bi-filar suspension, or may be retained in place by jewel and pivot bearings. If suspended, a small mirror is attached to the movable element and the deflection is observed by means of a telescope and scale, or, by the use of a mirror in connection with a lamp and scale. The pivoted form of galvanometer is usually provided with an indicating pointer, which moves over a graduated scale.

In the pivoted form the current is lead into, and conducted from, the movable coil by means of fine springs, which also serve as the retarding force; while, in the suspended form, the suspension forms one conductor, the other being a small strip or spring attached to the bottom of the coil. In the latter type, the spring, assisted by the reactance of the suspension to torsional influence, is the retarding force.

The type of galvanometer selected should be given careful consideration, as the best results are obtained only when the sensibility and resistance of the galvanometer is suited to the resistance of the potentiometer. Low resistance galvanometers should be used with low resistance potentiometers. The best form is the D'Arsonval wall type, fitted with a lamp and scale, though the portable, pivoted movable coil type may be used to advantage under some conditions.

The lamp and scale device can be arranged to take up but little room, and is superior to the telescope and scale method for various reasons, among which may be cited the following: A very slight deflection may be magnified by increasing the distance of the scale from the mirror; it is less tiresome on the eyes of the operator and quicker to operate, since the deflection can be seen from any position; it enables two persons to simultaneously ascertain when a balance has been obtained; the latter consideration is of some importance when operators are being trained, or when it is desirable for an observer to check the results obtained by the operator.

The auxiliary battery used in connection with a potentiometer is of great importance, since, for accurate measurement, the current must remain constant. It will be found advantageous to provide a cell, the capacity of which is in excess of that actually required, as the current under such conditions is rendered more stable than when a smaller cell is used. A storage battery of 2 to 20 ampere hours capacity is sufficient, provided the accumulator has a very small self-discharge. To keep the self-discharge to a minimum, pure acid should be used, and the employment of horizontal separators avoided, as they tend to increase the accumulation of sediment. A cell in which the elements are bridged by sediment from the plates will deteriorate rapidly. The specific gravity of the electrolyte should be 1,200, in order that the electromotive force may be

maintained between 2 and 2½ volts. It is advantageous to keep the cell at a temperature as constant as possible, since 1° of temperature rise increases the potential of a battery, having a specific gravity of 1,200 by

FIG 176.—Types of Standard Resistances.

.003 volts. The cells should be kept permanently in circuit in order that the polarization which increases for some time after the cell is put in service may reach a state of stability.

For **the measurement of current** by means of the potentiometer, **resistance standards** are required. As usually constructed, standard resistances are made by brazing thin sheets of manganin resistance to suitable terminals. Some types are immersed in oil and cooled by water circulation, while others are of such size as to carry their full rated current without artificial cooling (Fig. 176).

Manganin is an alloy composed of 84% copper, 12% manganese, and 4% nickel. It is best adapted for standard resistances, by reason of its low temperature coefficient, low thermal voltage to copper, and permanency of resistance when properly aged. Fig. 177 shows a type of air cooled standard, and illustrates the scheme employed by some manufact-

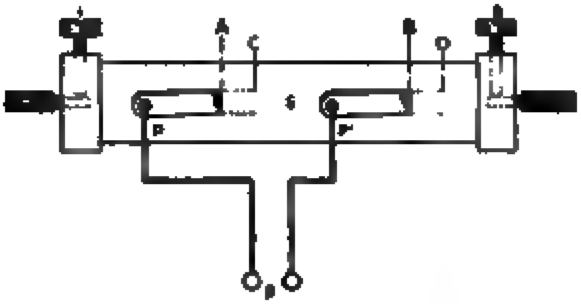


Fig. 177.—Diagram of Adjustable Standard Resistance.

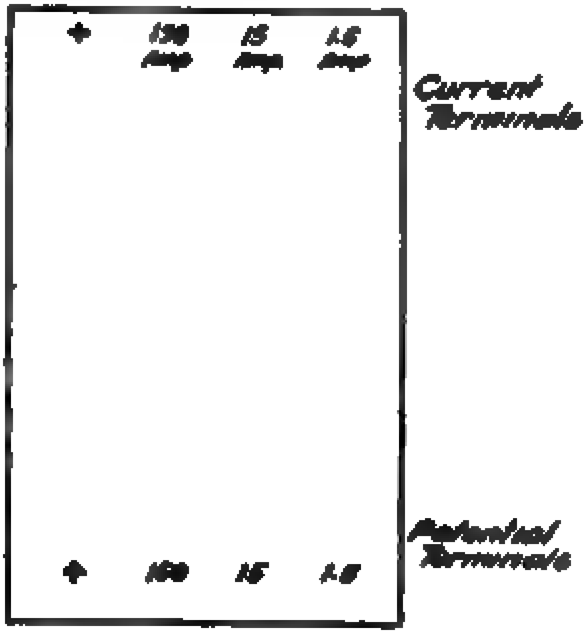


Fig 178.—Combination of Shunts for Measurement of Current.

urers for adjusting the resistance thereof, which has many advantages over the usual method of cutting or drilling.

S is a manganin strip, *I I'* copper terminals for connecting the current leads, and *p p'* are lips out from the strip *S*, and to which the potential leads *P* are brazed. The potentiometer is connected to the potential posts *P*.

The resistance between *A* and *B* is adjusted to be an even fraction of an ohm. This resistance is so chosen that, in order to determine the current passing through the shunt after having obtained a balance of the galvanometer, it is only necessary to multiply the potentiometer reading by a simple factor. Thus, if a .01 ohm resistance is used, the potentiometer reading multiplied by 100 gives the current in amperes. If the re-

sistance between p and p' is for instance .01005 ohms, cutting S in the direction of the dotted lines A C will tend to reduce the resistance. If the the slots are made too long, the resistance between p and p' will be less than .01 ohms. It can be raised, however, by cutting S along the dotted lines B D until the desired value is obtained.

Air cooled standards, from the standpoint of convenience are preferable to the oil or water cooled type, although the latter are usually constructed to give a higher voltage drop. It may be urged that the advantage of the higher voltage outweighs the disadvantage of providing for oil and water cooled device, but, with a low resistance potentiometer, and a sufficiently sensitive galvanometer, the air cooled resistances leave nothing to be desired in the way of accuracy, as this type can be constructed with sufficient voltage drop to obtain high accuracy for even the largest capacities.

The capacity of the standard resistances selected will depend upon the value of the current to be measured. In general, standard resistances may be used in connection with a potentiometer for current measurements as low as 5% of their rated capacity, if the potentiometer is one of the shunted type, provided with a low scale. If it is not one of this type, the employment of standard resistances at less than 10% of their capacity is not very satisfactory.

It is best to provide at least two resistances for each of the capacities desired. One set can be retained as reference standards, and the other used as working standards. In many cases one set of standards may be sufficient, but, when duplicate resistances are not provided, the accuracy of any shunt can only be determined by comparison with those immediately above or below it in size; in the event of one or more standards developing errors, due to accidental overload or mechanical injury, the absence of a duplicate renders the accurate checking of those of greater capacity than the damaged ones a difficult matter. This objection does not apply to cases where the resistances are submitted at frequent intervals to a standardizing laboratory for test.

Resistances used in connection with millivoltmeters for the measurement of current are usually termed **shunts.** Separate shunts may be obtained for any current capacity, but more often several shunts are inclosed in one case. The use of such a combination of shunts is a convenience, as the employment of the common terminal for one side of all shunts renders changing from one capacity to another a simple matter. The usual arrangement of a combination shunt is shown in Fig. 178.

A, B and C are potential taps, usually of manganin wire, brazed to the resistance strips at points which will give approximately the same potential drop with full load current in their respective shunts.

When a shunt of this type is used in connection with a particular millivoltmeter, the scale of the latter is usually marked with a number of divisions, which is an even multiple of all the shunts used. In the case of the shunt illustrated the instrument scale would have 150 divisions.

A simple method of adjustment is to vary the resistance of the po-

Fig 179.—Arrangement of Permanent Magnet and Movable Coil in D'Arsonval Type of Instrument.

Fig 180 — Movable Element in D'Arsonval Type of Instrument Keystone.

tential taps *A*, *B* and *C* until the indicator of the millivoltmeter indicates 150 divisions when full load current is passed through each shunt.

Portable and semi-portable, or laboratory, types of indicating electrical instruments may be divided into **three classes.** The **first** being capable of use on continuous current only; the **second** on both continuous and alternating current, and the **third** on alternating current only.

The permanent magnet movable coil type of instrument is the

standard form for the commercial measurement of continuous voltage and current.

The principle of operation is similar to that of the D'Arsonval galvanometer, a pivoted movable coil being arranged to swing through the field produced by a fixed permanent magnet (Figs. 179 and 180).

The motion of the coil is opposed by flat spiral springs, which also serve as conductors, connecting the coil to the circuit. These springs are so arranged that, when the movable coil is deflected, they are twisted in

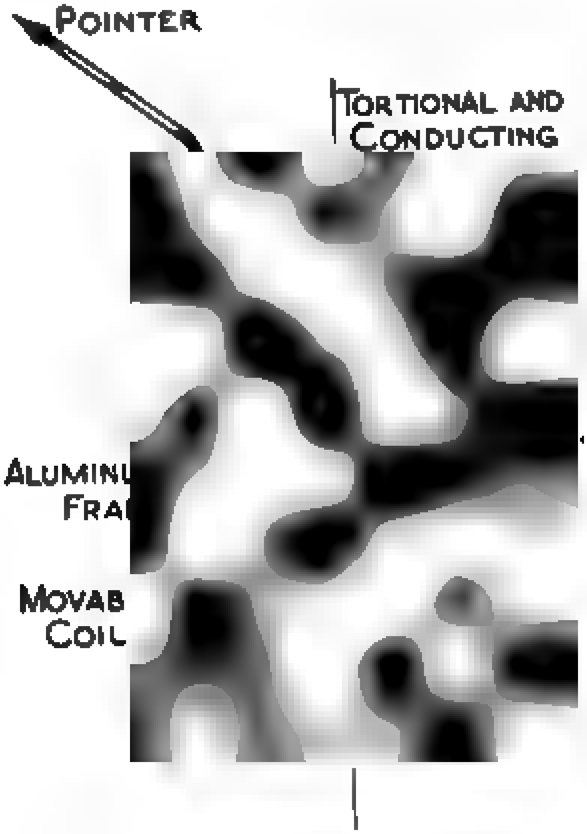


FIG. 181.—Form of Movable Element in D'Arsonval Type of Instrument.

opposite directions, one being wound and the other unwound. The effect is such as to neutralize the effect of variation of the springs from the law of proportional deflection.

Fig. 181 shows a standard form of construction of the movable element of this type of meter, and illustrates the usual arrangement of the springs and the rectangular aluminum frame over which the coil is wound.

Pole pieces of soft iron are usually attached to the permanent magnet; these pole pieces being such shape as to render the field in which the movable coil turns one of uniform intensity.

The deflecting torque is proportional to the product of the strength of the magnetic field and the current in the movable coil; and the counter

torque of the springs is approximately proportional to the angle that the movable coil is deflected from its initial position; therefore, the deflection of the movable element is approximately proportional to the strength of the current, and the scale divisions are uniform.

For the purpose of rendering this type of instrument "dead beat" or aperiodic, the movable coil is wound upon a light rectangular aluminum frame in which eddy currents are generated when it moves in the field, produced by the permanent magnet. These currents are of such magnitude as to influence the movable element to come to rest almost instantly and without friction.

Since the instrument gives a deflection proportional to the strength of the current flowing in it, this type is always in reality an ammeter, whether used as such or as a voltmeter.

In a voltmeter the coil on the movable element consists of many turns of fine wire, in series with which is a resistance; the value of the resistance is such that, when the maximum required voltage is applied, it limits the current through the movable coil to that necessary to produce full scale deflection. The scale may then be marked directly in volts.

In an ammeter, when a small current is to be measured, the total current may be passed through the coils on the movable element, but when the current exceeds that required to produce full scale deflection, a portion must be diverted through a circuit connected in parallel with the circuit of the movable element. By this method a current of any desired magnitude may be measured by passing it through a suitable resistance known as a **shunt.** The employment of a shunt eliminates the necessity of providing instruments with movable elements of sufficient size and weight as to carry unduly large current.

Two small **leads** run from the shunt to the instrument. These leads must be considered as a part thereof, as any alteration in their length, cross section, or material will change their resistance, and will affect the calibration of the instrument.

In order that the shunts be made as small as possible, the torque of instruments used in connection therewith is lower than that of ordinary voltmeters, and the springs are somewhat weaker. The reduction in torque is affected by winding the movable coils of meters used for measuring current with a less number of turns, as is the case with voltmeters, and using somewhat larger wire.

A movable coil instrument, designed for the measurement of current in connection with a shunt, is termed a **millivoltmeter;** the combination of instrument and shunt is used as an ammeter.

The value of current which may be passed through the movable element without the use of a shunt may be determined by Ohm's law

$I=\frac{E}{R}$, where E is the potential required to give full scale deflection, and R the resistance of the instrument. Where a millivoltmeter is used, E is equivalent to the full load drop of the shunts used in connection therewith.

It is customary to mark the scale of such an instrument in amperes when it is to be used in connection with certain shunts especially calibrated for it. Sometimes, however, the scale is marked in millivolts, and in this case the instrument can be used in connection with any desired shunt, if the resistance of the instrument, leads, and shunt are known. When so used, **the combined resistance** may be determined by the formula:

$$\text{Combined resistance } R=\frac{r\,r'}{r+r'}$$

where r = resistance of millivoltmeter and leads, and r′ = resistance of shunt. The current flowing through the combined resistance can then be determined by Ohm's laws, $I=\frac{E}{R}$, where R is the combined resistance above determined, and E is the volts observed on the millivoltmeter.

Another method of using a millivoltmeter in connection with shunts consists of dividing the scale into some number of divisions, which is a multiple of the capacity of all the shunts of uniform voltage used in connection therewith, proper multipliers being used for each shunt. The error in the latter method caused by not taking into consideration the decrease in the combined resistance R by the addition of the millivoltmeter circuit is negligible except when used with small capacity shunts, and can be checked by the above formula, or can be determined by comparison with standards.

Continuous current instruments of permanent magnet type are available from a number of manufacturers. **The general features to be considered in selecting** such an instrument are ruggedness of construction, permanency of calibration, legibility of scale, dampening, weight and the facilities which the design affords for repair and adjustment. Voltmeters should be chosen with fairly high resistances, although extremely high resistances are not especially desirable in ordinary commercial testing, as the decrease in the energy consumed by the instrument is effected at the cost of reduction in torque.

The most suitable resistance values are 100 to 150 ohms per volt. Laboratory instruments for current measurement used in connection with shunts should require at least 100 millivolts to produce full scale

deflection, as instruments operating with less than this value are not usually satisfactory with respect to temperature compensation.

For **secondary standards for continuous current** the type commonly known as the "laboratory standard" gives very satisfactory results (Fig. 182). Instruments of this class, when used in current measurements. should be provided with a large number of shunts, in order that the necessity of working at less than one-fifth of the scale be obviated. These instruments, when permanently set up and checked in position, may be

Fig. 182.—Secondary Standard Voltmeter, D'Arsonval Type, Weston.

depended upon to maintain an accuracy of one-tenth of one per cent of full scale deflection (Fig. 183).

Secondary standards for alternating current measurements must be capable of measuring both continuous and alternating currents, as they are to be used for transfer instruments; that is, they are standardized with the primary standards on continuous current, and used to check portable alternating current instruments. This consideration limits the choice of alternating current secondary standards to a few types, the most satisfactory of which are **the zero reading elec trodynamometer instruments** constructed upon the **Kelvin balanc**

principle; though electro-dynamometer **instruments of the scale and indicator type** are capable of giving excellent satisfaction.

The action of the electro-dynamometer depends upon the force exerted by two circuits when traversed by current, or by a portion of a circuit upon another portion of the same circuit. Such instruments contain one or more fixed coils which set up a magnetic field proportional to the current flowing, and a movable element of one or more coils placed within this field, through which the current is also passed.

An instrument in which the movable and fixed coils are connected in series constitutes an ammeter, which, when properly designed, may be used to measure continuous current or alternating current of any frequency or wave form. Thus it may be calibrated with the primary standards on continuous current and used as a secondary standard of precision for alternating current.

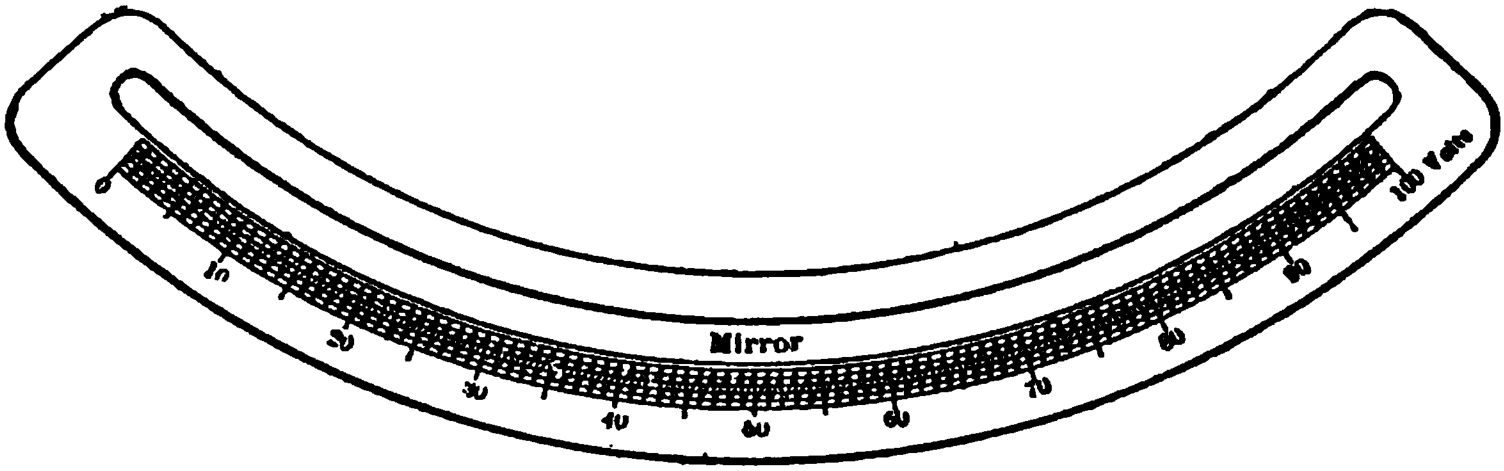


FIG. 183.—Type of Scale Used in Secondary Standard Instrument Showing Method of Subdividing and Mirror. Weston.

The Kelvin ampere balance and Siemens dynamometer are typical of two methods of arrangement for the fixed and movable coils (Figs. 75 and 76, Chapter III, and Fig. 184). The Kelvin balance contains six coils, four of which are fixed and two are movable. The movable coils are attached to the extremities of a horizontal beam, which is suspended by ligaments, so that each coil is midway and parallel between two fixed coils. The coils are astatically arranged, thus rendering the indications free from the influence of stray magnetic fields, having equal effect on the two coils.

When the movable and fixed coils are connected in series, connection to the movable coil is made through mercury cups, as in the Siemens dynamometer or by means of suspending ligaments, as in the Kelvin balance, or by flexible conductors or springs, as in other types of instruments. The Siemens dynamometer and Kelvin ampere balance are practically obsolete for central station service due to the fact that they are slow and

inconvenient to use, and require exceptionally steady current. The dynamometer, when used on continuous current, is affected by stray fields.

TORSION HEAD

FIG. 184.—Arrangement of Coils of Siemens Dynamometer.

while the Kelvin balance changes with temperature, and has a frequency error which increases with the capacity of the instrument.

FIG. 186.—Siemens [illegible]

In the Kelvin balance the retarding force is gravity; in other types of electro-dynamometers springs are used.

In the Siemens dynamometer the control spring is attached to the movable coil, and to a movable torsion head, which is fitted with a pointer of some form. An indicator attached to the movable coil indicates its position when no current is flowing. Under the influence of current the movable coil tends to place itself at right angles to its initial or zero position, and is brought back to zero by shifting the torsion head. The pointer on the latter shows the angle through which the torsion head is turned. This angle is equal to the product of the square of the current, and a constant—the value of which is determined by calibration.

Fig. 186.—Elements of Ammeter, Kel in Balance Type, Westinghouse.

In the scale and indicator type, under the influence of current the movable coil takes up a position where the torque produced by the effect of current in the fixed and movable coils is just balanced by the counter torque of the control springs. The scale is marked with the value of current or voltage required to produce this deflection. When no current is flowing, the control springs return the movable coil to its initial position, and the indicator indicates zero on the scale.

Fig. 185 illustrates a standard form of current dynamometer and relative position of the fixed and movable coils.

The arrangement of the elements in the Westinghouse **precision ammeter** is shown in Figs. 186 and 187. This type of instrument is constructed on the Kelvin balance principle.

The elements of the **electrodynamometer voltmeter** as typified by

instruments manufactured by the Weston and Keystone instrument companies are shown in Figs. 188 and 189. It will be noted that in the Siemens dynamometer the movable coil is outside the fixed coil, while in the voltmeters illustrated, the fixed coils enclose the movable coil.

The torque of instruments in which the fixed and movable coils are in series, is proportional to the square of the current, and since the retarding force is approximately proportional to the angular deflection of the movable coil from its initial position, it follows that the scales of such instruments are not uniform. Another cause for non-uniformity of scale inherent to electrodynamometer instruments of the scale and indicator type is the fact that the movable element, in turning, is deflected through a magnetic field of variable intensity. Such instruments have scales which are usually open in the center, and contracted at the high and low points.

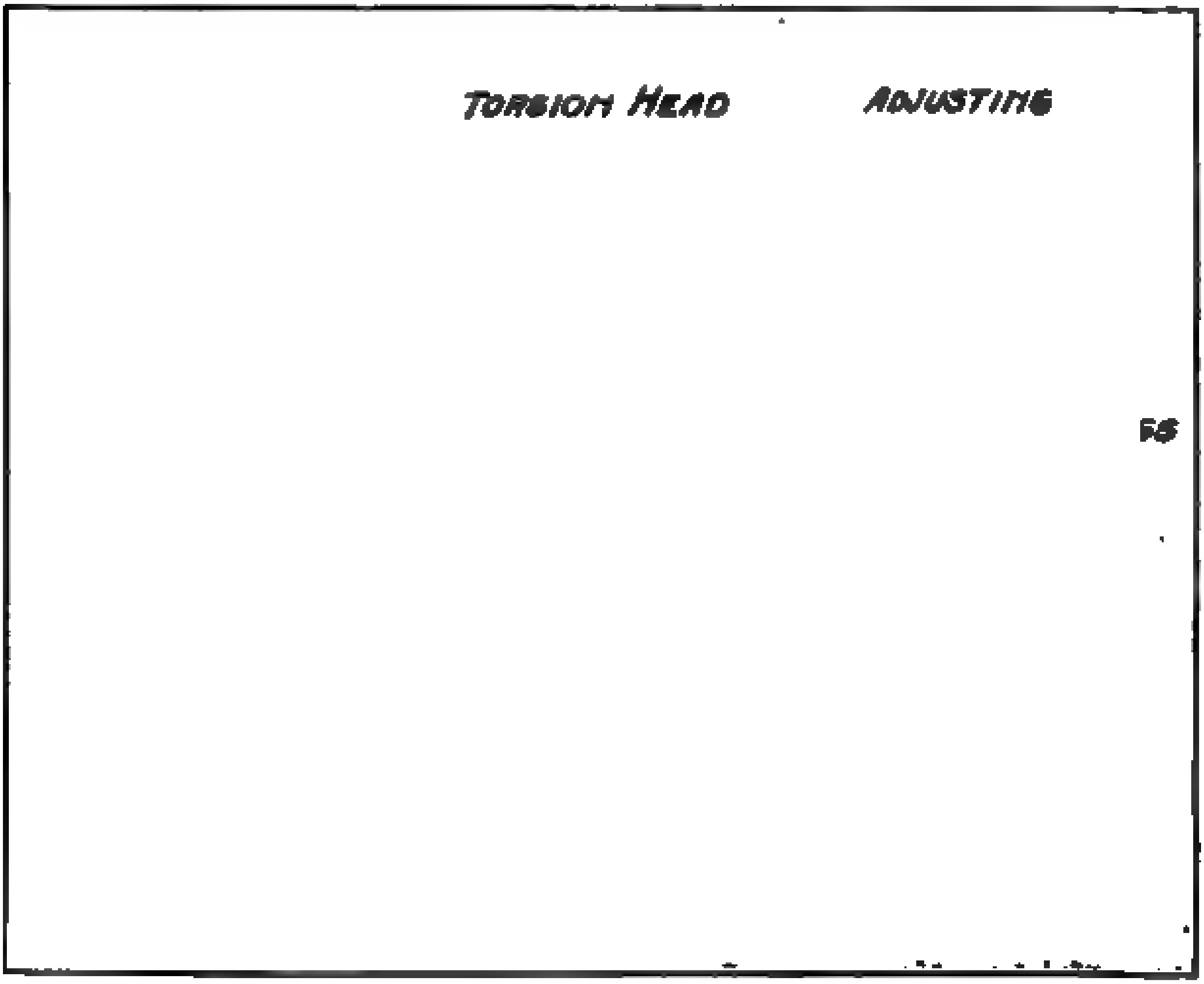


FIG. 187.—Annotated View of Ammeter, Kelvin Balance Type, Westinghouse.

The Kelvin balance type of instrument is not influenced from this source, as its measurements are determined by the angular deflection

FIG. 188.—Annotated View of Voltmeter, Electrodynamometer Type, Weston.

FIG. 189.—Annotated View of Voltmeter, Electrodynamometer Type, Keystone. A, Scale Face; B, Slot for Mirror; C, Air Chamber for Damper; D, Springs; E, fixed Coils; F, Indicator; G, Movable Coil.

of the springs; the movable coil being in the same position with respect to the fixed coils for all measurements.

Special devices are adopted by various instrument makers to obtain an approximately uniform scale. The Keystone Instrument Company, for instance, for their voltmeter, use a combination of springs to obtain the desired effect. This combination consists of two springs so related to one another that, when the indicator is at zero, it is held in a dynamic rather than in a static state of rest. One spring uniformly opposes the movement of the movable coil, while the other spring assists the movable

FIG. 190.—Movable Element Showing Springs and Damper of Voltmeter, Electrodynamometer Type, Keystone.

element through the first half of the scale, then acts with the spiral spring and helps oppose its movement through the second half of the scale. Thus the control is weak when the deflecting forces are weak, and automatically increases in strength when the deflecting forces increase in strength (Fig. 190).

In the Siemens & Halske instruments, the coils are so shaped as to obtain increased torque at the high and low parts of the scale, and thus make the scale divisions more nearly equal (Fig. 191).

The electrodynamometer voltmeter has fixed and movable coils of fine wire, connected in series with each other, and with a non-inductive resistance of low temperature coefficient. This resistance is of high value in order to reduce the ratio of inductance to resistance to a minimum, and thus render the instrument free from errors on circuits of ordinary commercial frequency

In **electrodynamometer wattmeters** for the measurement of alternating current power, the stationary element consists of comparatively few turns of heavy wire, and is connected in series with the load to be measured (Fig. 192).

The movable element consists of a large number of turns, and is similar to that of a voltmeter. It is connected across the line in series with a non-inductive resistance of low temperature coefficient. This resistance may be enclosed in the instrument case, or may be external in the form of a multiplier.

FIG. 191.—Voltmeter, Electrodynamometer Type, Siemens & Halske.

The supporting frame of well designed instruments is either made of wood or some high resistance metal, free from magnetic properties, thus eliminating the errors due to eddy currents.

The voltage circuit of an indicating wattmeter of the electromagnetic type contains in addition to the movable coil of the instrument which is inductively wound, a so-called non-inductive resistance. The latter is very high in comparison to the inductance of the movable coil, so that the total impedance of the movable coil circuit is practically equal to the non-inductive resistance. When the inductance of the voltage circuit as a whole is negligible, the instrument indicates correctly at all values of power-factor. If the non-inductive resistance is not high enough, the inductance of the movable coil may introduce a perceptible lag in the cur-

rent in the voltage circuit. Some types of non-inductive winding introduce a measurable capacity into the circuit, and this may cause a leading current in the voltage circuit. In either case a resultant error is intro-

FIG. 192.—Portable Wattmeter, D'Arsonval Type, Keystone.

duced which increases very rapidly as the power-factor is lowered, and is expressed by the following formula:

$$\text{Percentage error} = \tan \phi \tan \alpha \times 100,$$

where ϕ = angle of lag in receiving circuit,

α = angle of lag in voltage circuit.

Angles of lead are considered to be negative.

In the Kelvin balance type of electrodynamometer wattmeter, as typified

by the Westinghouse precision instrument, the torque is proportional to the product of the current in the fixed and movable coils.

As the position of the movable element for any indication is the same —in a highly concentrated field of uniform intensity the scale divisions are uniform and subject to only a slight deviation of the springs from the law of proportional deflection.

In other types of electrodynamometer wattmeters, as typified by those of the Weston Electrical Instrument Company, the torque is also proportional to the product of the currents in the fixed and movable coils, but the scale is not uniform, due to the fact that the movable element, in turning, is deflected through a field of varying intensity. Such instruments have scales which are open at the center, and contracted at the high and low points.

Electrodynamometers in which the coils are not astatically arranged are subject to the influence of stray fields, and if used on continuous current, reversed readings must be taken in order to eliminate the effect of the earth's field.

There is more or less of a difference of opinion among users and manufacturers of instruments concerning the **relative merits of the dynamometer or zero reading type** of construction **and the** direct swing or **scale and indicator type.**

The zero reading type of instrument is especially applicable in making tests when the voltage or load must be maintained at a constant value. In this class of service, the pointer attached to the torsion head is set at the desired point on the scale, and the operator has then only to manipulate the controlling devices until the indicator attached to the movable system indicates zero.

It should be borne in mind that instruments of the Kelvin balance type have their coils astatically arranged, thus insuring freedom from the influence of external magnetic fields, when these have equal effect on all the coils. Other types of instruments are strongly affected by external fields.

Most instruments of the direct swing type are characterized by low torque and light delicate construction of the movable element. These characteristically weak features are the result of the necessity of so constructing the elements as to permit a large angular deflection of the movable coil. The large angular movement brings the coil into a widely distributed non-uniform magnetic field, which is much weaker than that secured by the balanced dynamometer construction.

Another point worthy of consideration is the effect of accidental overloads of momentary duration. In the case of direct swing instruments the indicator is very likely to be bent, necessitating repair and recalibra-

tion prior to further use. In the Kelvin balance type, the angular deflection of the movable element is small, and the construction is so rugged that in most instances the accuracy of the instrument remains unimpaired.

In general, it may be stated that the relative advantages of these two types of construction depend entirely upon the service required of them. **Instruments intended for use in a laboratory** where speed or convenience of manipulation is subservient to high accuracy are most satisfactory when of the zero reading type. For use on circuits which fluctuate, the indicating, scale and indicator type are probably best.

The Westinghouse Electric & Manufacturing Company's line of precision instruments are representative of the **best form of secondary standard transfer instruments** available for central station service.

The merit of this type of instrument lies in the advantages afforded by its principle of operation and in the quality of material and workmanship employed in its construction.

The relative advantages of the zero reading and scale and indicator type of instrument have been discussed, and it is clear that where other characteristics are equal, the more rugged construction of the Kelvin balance type renders this species of instrument most desirable for laboratory service.

In this precision instrument, the movable system consists of two coils, which are attached to an aluminum frame and supported by a ball and cup jewel bearing. Each movable coil is placed vertically between two fixed coils, and the connections are such that each movable coil is attracted by one fixed coil and repelled by the other.

The instruments are zero reading, the movable element being deflected from its position of rest when current passes through the coils. The indications are determined by the deflection of the control spring to return the movable system to zero. An indicator, fitted with a fine cross-hair, is attached to the movable element, and by its position over the zero line of the scale, indicates when the torque produced by the current in the coils is exactly balanced by the counter torque of the controlling springs.

The scales are of silvered metal, the divisions of which are cut by an engraving machine, thus insuring exact uniformity (Fig. 193). A vernier enables tenths of divisions to be read with exactitude. The voltmeters and ammeters are provided with double scales, one reading in divisions and the other in volts or amperes. The scale marked in divisions is used when most accurate results are required, the value of the indication being determined by the calibration curve, constant, and a table of square roots

which accompanies each instrument. The scale of the wattmeter is uniform, and the indications are determined by the calibration curve and constants supplied by the maker.

Being constructed on the Kelvin balance principle, the indications of these instruments are unaffected by the wave form or stray magnetic fields, having equal effect on all the coils.

FIG. 193.—Scale Used in a Null Type of Instrument, Showing Double Scale and Vernier, Westinghouse.

The fixed coil supports are composed of a high resistance alloy, which avoids errors due to eddy currents and provided a rigid non-warping frame for the elements.

The voltmeter, and the potential circuit of the wattmeter, are provided with non-inductive external resistances. The ratio of this resistance to the inductance of the potential circuit is such that the instruments are unaffected by changes in frequency. In the case of the wattmeter this property insures accuracy on very low power-factors.

The external resistance for voltmeters and wattmeters is composed of manganin, the temperature coefficient of which is negligible. Temperature effects, due to the heating of the coil and control springs, tend to cancel; the resistance coefficient being positive and that of the springs negative; the combined coefficient of resistance and springs being about 0.03 per cent per degree *C*. This coefficient is negative, less energy being required for a given deflection as the temperature increases.

The instruments are provided with thermometers with which the temperature of the springs may be measured, so that the proper correction may be applied.

Precision voltmeters and wattmeters are of rugged construction and

FIG. 194.—Comparator Equipment for the Measurement of Alternating Currents by Comparison with Standardized Direct Current Instruments. Leeds & Northrup.

may often be subjected to momentary overloads, without having their accuracy permanently impaired. Ammeters of this type must be guarded against overload, however, as the flexible conductors which carry current to the movable coil are likely to be damaged.

In **the hot wire type of instruments** the deflection depends upon the expansion of a wire heated by the passage of current. (See Chapter II.) Instruments based upon this principle are independent of frequency, wave form, and stray magnetic fields, and may be calibrated upon continuous current. A marked advantage is, that they may be used in connection with shunts for measuring alternating current of ordinary fre-ncies.

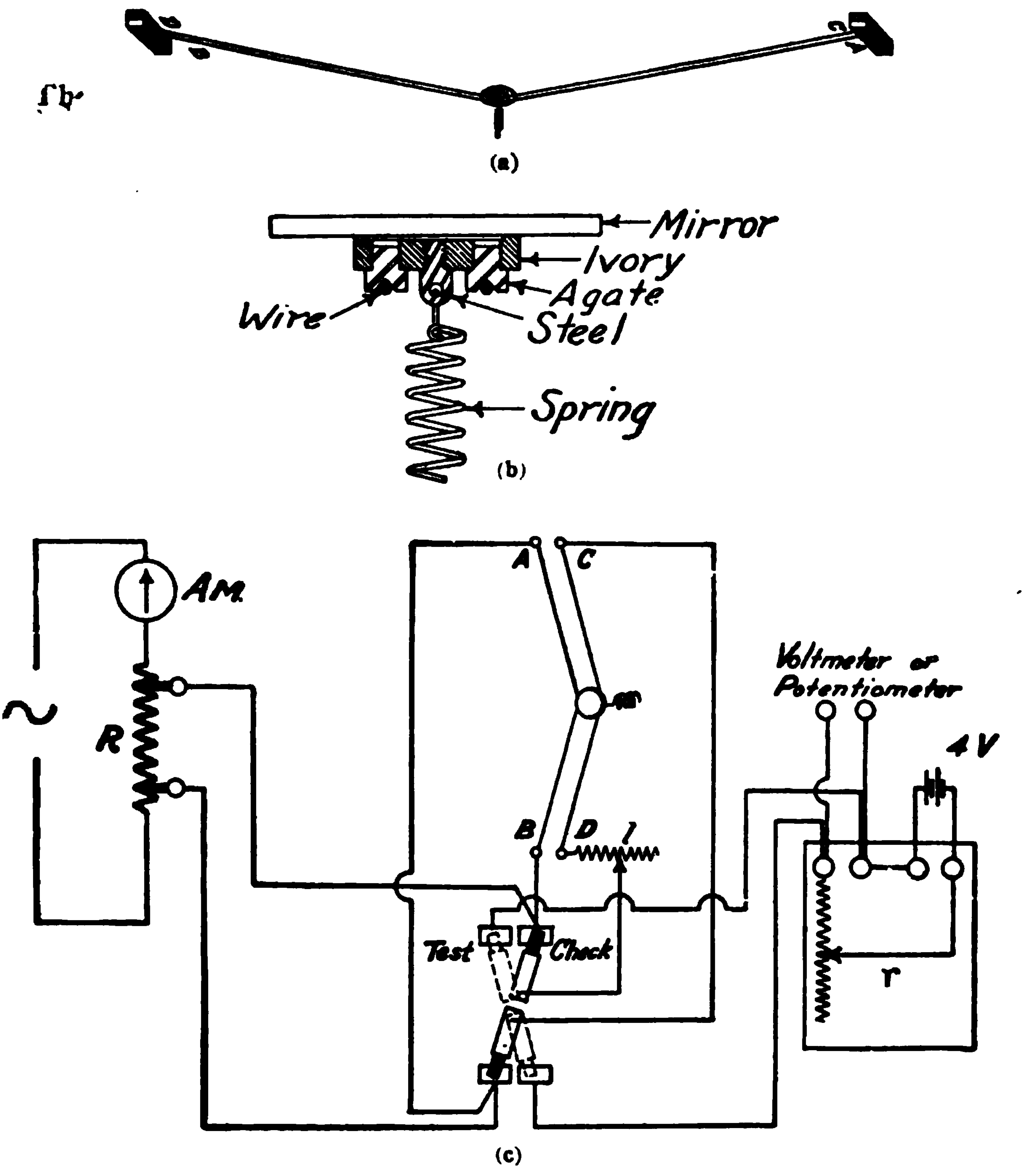


FIG. 195.—Comparator Diagrams: Showing the essential feature of the instrument, which is a sensitive device for detecting differences between two small currents and for showing when they are equal. Its action is the same whether the currents be direct or alternating; consequently, it can be used to show equality between small direct and alternating currents.

(a) Two wires, A–B and C–D, of equal length, diameter and resistance are stretched, as shown, about 5–32 inches apart. They are pulled back at the middle point by a cross piece, resting on both. A spring attached to the cross piece keeps a constant tension on the two wires. A mirror is mounted on the cross piece, as shown in detail in (b). If one wire elongates more than the other, the mirror will tilt and a very slight tilting can be observed by a lamp and scale. Equal currents flowing through both wires will cause equal heating and equal elongation but no deflection, but a slight difference in the currents in the two will cause unequal elongation and a deflection.

(c) Arrangement of comparator for the standardization of an alternating current ammeter.

The Leeds & Northrup Comparator is a type of **hot wire instrument designed for the standardization of alternating current voltmeters and ammeters,** and for the determination of the ratios of instrument transformers (Figs. 194 and 195). External to the instrument itself are non-inductive resistances, the number and capacity of which varies with the quantity of current, or voltage to be measured.

This device is slow in operation, must be guarded against overload, and must be used in conjunction with a potentiometer to attain an accuracy of 0.2 per cent.

Fig. 196.—Voltmeter for very High Potentials, Electrostatic Type, Westinghouse.

As a class, these instruments should not be considered as satisfactory standards for central station use. Among the disadvantages may be mentioned that they have a limited range, no overload capacity, are slow in operation, and their mechanical construction is such as to render repairs difficult.

Another type of instrument which may be used upon continuous, or alternating, current is known as **the electrostatic type** (Figs. 196 and 197). In the Kelvin multicellular pattern, the action depends upon the attraction of oppositely charged bodies, and the repulsion of similarly charged ones. The forces are so small that **electrostatic**

ammeters are not practical, but **electrostatic voltmeters** can be made for potentials in excess of 300 volts, which will operate satisfactorily.

The great advantage of this type of voltmeter is, that it consumes no energy when used on continuous current circuits, and an extremely small amount when used on alternating current circuits. It is not affected by frequency changes, wave form, or stray magnetic fields. For very high voltages the electrostatic voltmeter can be used to great advantage if it is not desired to use voltage transformers. Wattmeters may

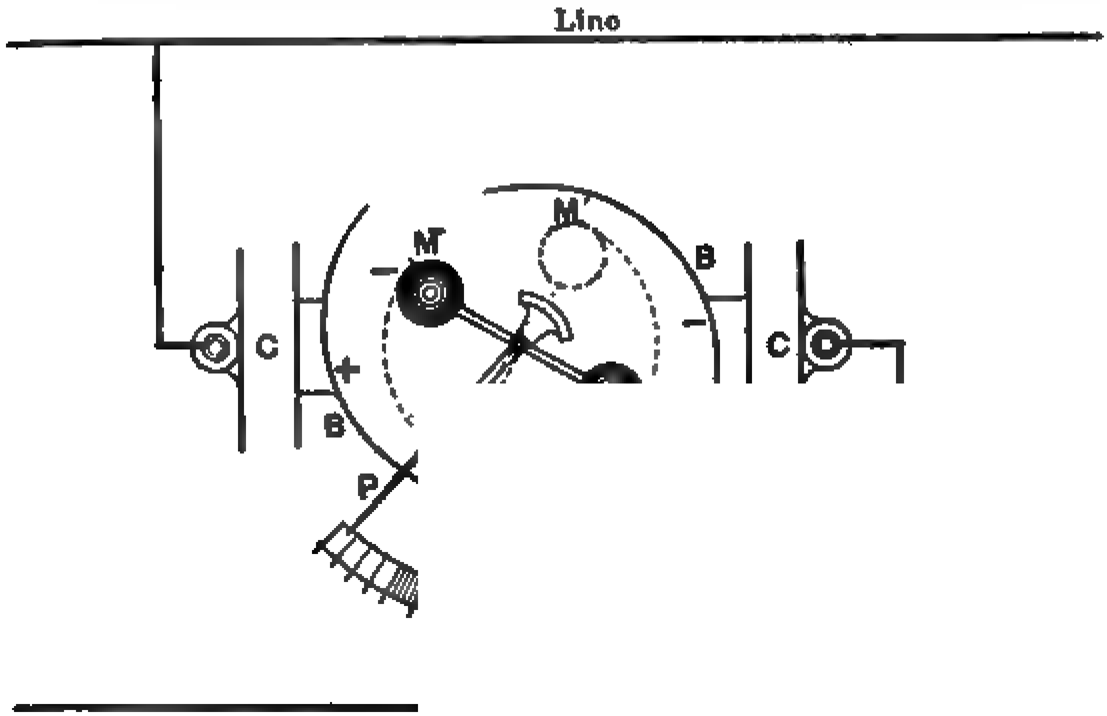


FIG. 197 —Elements of Voltmeter, Electrostatic Type, Westinghouse.

be constructed on the electrostatic principle, but are not suitable for practical application.

Calibrated resistances, properly used, afford an excellent means of comparing alternating current instruments with continuous current standards. The earliest forms of calibrated resistances consisted of banks of seasoned and calibrated incandescent lamps. These possessed disadvantages arising from their bulk, liability to breakage and variations in resistance due to overload.

In **the latest forms of calibrated resistances,** resistance units composed of zero temperature coefficient metal, capable of carrying their rated watts continuously without change in resistance, and unaffected by repeated heating and cooling, are employed. The units are so constructed as to be immune from accidental damage, and are

mounted in a protecting box or frame, with suitable switches for connecting the various ranges in circuit. The switches must have a negligible contact resistance.

The connecting leads are a part of the calibrated resistance, and should be maintained in perfect condition.

Where it is desired to avoid the use of corrections, a convenient and reliable means of adjusting the resistances should be provided, in which case the resistances should be readjusted whenever found in error.

FIG. 198.—Annotated View of Induction Type of Instrument. Westinghouse.

The accuracy with which the load is determined is, assuming the resistance to be correct, dependent only on the accuracy of the voltmeter; but it should be borne in mind that a given percentage error in calibrating, or in reading the voltmeter affects both the voltage and current.

Where the observed voltage is in error, the percentage of correct watts indicated may be determined by the following formula where

$X =$ error in volts, and
$E =$ true volts.

If observed volts are greater than true volts, the percentage of correct watts $= 100 \dfrac{(E+X)^2}{E^2}$. If observed volts are less than the true volts, the percentage of correct watts $= 100 \dfrac{(E-X)^2}{E^2}$

Instruments operating only on alternating currents are known as **induction instruments.** Their action depends upon the interaction of inducing and induced currents. The usual form, typified by those of Westinghouse manufacture, contains a laminated iron core, surrounded

Fig. 199.—Movable Element of Instrument Shown in Fig. 198.

Fig. 200.—Diagram of Windings of Instrument Shown in Fig. 198.

by one or more coils of wire (Figs. 198, 199 and 200). An alternating magnetic flux is set up in the air gap of this core when current flows through the coils. The effect of a rotating field may be secured through the action of more than one group of coils, in which the currents differ in phase or a single coil may be used with fixed copper dampers in which induced currents are set up.

The resultant action of the flux, due to the coil, and that due to the induced currents in the dampers, produces the effect of a rotating field. In this field, a drum or disk—usually of aluminum—is supported by

pivots. The rotating field, reacting upon the currents induced in the movable element, produces rotation. In indicating instruments the rotation is opposed by a spring. An inherent defect of this type of instrument is that it tends to vary somewhat with change of frequency. This type of instrument possesses the advantage of a nearly closed magnet circuit and an extremely long scale. The movable element has no windings, and hence requires no provisions for conducting current to and from it. These instruments are not suitable for circuits of varying frequency, and they must be calibrated by comparison with standards of the electrodynamometer type.

Instruments of the electromagnetic type, such as the Thomson **inclined coil voltmeters and ammeters,** and Weston alternating current patterns, depend upon the action of the flux set up in a coil traversed by current upon one or more pieces of soft iron.

The fundamental principle of operation is such that this form of instrument will operate on continuous current, but the results obtained when so used cannot be relied upon closer than two or three per cent. On account of hysterisis, the means of reverse readings on continuous current does not give an accurate test of the performance on alternating currents, so, when intended for use on alternating current, they should be calibrated by means of transfer instruments which have been checked with continuous current standards.

These instruments—the electromagnetic and induction patterns—have a certain definite use in the laboratory as **working instruments,** but should not be considered as reliable standards unless calibrated by means of transfer instruments on a circuit of the same frequency as that on which they are used. They should be selected with special reference to performance under conditions of variations in wave form and frequency, and also with regard to dampening, since most alternating current instruments require auxiliary dampening devices, some of which are more satisfactory than others.

Those operating upon the electromagnetic system are less affected by frequency and wave form variation than are those of the induction type; the latter, however, have the advantage of an extremely long open scale, much higher torque, more rugged construction, and can be arranged for two capacities by means of a series and multiple combination of windings.

A rotating standard is a portable form of watt-hour meter, fitted with graduated dials, on which revolutions and fractions of revolutions of the moving element are indicated by means of dial hands (Chapter XVI).

Rotating standards are usually provided with a number of coils so

as to obtain various current capacities, and the potential winding arranged for use on 110 and 220 volt circuits.

Various means are employed in effecting the combination of the coils so as to obtain the different capacities. For instance, the Westinghouse rotating standard is provided with a drum switch which changes both the current and potential coils, and the Fort Wayne rotating standard was formerly provided with plugs, by means of which the current coils—the leads of which were fastened to contact blocks—were grouped in series and multiple series combinations. The present type is provided with separate terminals for the different current capacities.

This type of instrument affords a rapid, accurate means of testing watt-hour meters, which possesses many advantages over any other method. Among these are—that it is well adapted for use by one man, and that the results obtained by its use are independent of fluctuations in line voltage.

Rotating standards are peculiarly well adapted for use on alternating current circuits by reason of the simplicity of design afforded by the induction watt-hour principle. The use of rotating standards in continuous current testing is usually confined to tests on watt-hour meters under 150 amperes capacity.

In general, **the type selected** depends upon the type of service meter in use. It is obvious that a standard possessing the same characteristics as that of the meter under test may be used more advantageously than one in which the characteristics are different. Points to be considered in the selection of portable watt-hour standards include constants, capacity, accuracy, permanency of calibration, ease of manipulation to obtain various ranges, design and arrangement of the dial and indicator, weight, and general portability. The constants and characteristic load curve should be adapted to those of the service watt-hour meters. The instrument should have a number of current ranges, so as to enable the selection of suitable coils for testing meters of various capacities.

The relation of the various windings to each other should be investigated to eliminate the possibility of error in one or more range. The effect of changing from one range to another should be investigated to eliminate the possibility of error in one or more range. The effect of changing from one range to another should be effected in a simple manner, so as to avoid errors due to improper grouping of the windings, and care should be taken to consider the error in changing from one to the other.

In addition to the above, continuous current rotating standards should

FIG. 201.—Standard Clock.

be selected with special reference to the effect of temperature, external fields, and portability.

In some types of continuous current rotating standards, the tem-

perature error due to the heating of the armature circuit is negligible, and the only temperature error to be compensated for is that of the disk.

These standards are made with an armature wound with comparatively few turns of heavy wire and a resistance in series with the armature wound with wire of negligible temperature coefficient. The resistance of the armature is only a small portion of the total resistance of the circuit, and the wire with which it is wound is large enough to carry the armature current without any appreciable heating.

Any change in the temperature of the disk will cause a corresponding change in the eddy currents, and this will alter the drag of the meter. To compensate for this, a sliding contact with a pointer is placed on the rotating standard to cut in or out a portion of the negligible temperature coefficient resistance wire, thereby changing slightly the current in the armature circuit, so as to compensate for the changed drag.

The sliding contact plays over a scale calibrated in degrees and the pointer is set to correspond to the reading of a thermometer which is placed inside the rotating standard. Observations of the thermometer should be made during the test and care taken to see that the sliding contact is always set to correspond to the reading.

The master standard for the measurement of time should be a high grade standard clock, with a pendulum beating seconds (Fig. 201).

The clock should be provided with a contact device so that **secondary clocks** can be electrically operated therefrom, or time signals transmitted by means of relays, or telephones, when such is desired (Fig. 202).

Where a suitable type of **automatic relay** is used instead of a stop watch for laboratory tests on watt-hour meters, inherent errors in the watch and the personal error of timing are eliminated.

Fig. 203 illustrates a type of relay operated test circuit, which is used by the Edison Electric Illuminating Company of Boston, for comparing portable rotating standards with secondary standards.

Its operation is based on the testing formula,

$$\text{Watts} = \frac{3{,}600 \times K_h \times R}{S}$$

where K_h = watt-hour equivalent of one revolution of the moving element of the meter or the watt-hour constant, and

R = the number of revolutions of the moving element in time, S, seconds.

Of these various factors K_h is fixed by the construction of the meter.

while the watts, revolutions and time are variables, although any two of the latter may be fixed at any predetermined value.

It is customary for any given test to use a fixed value for R, allowing the watts and time to be variable, and determining their average value by indicating instruments and a stop watch. Of these, the value of

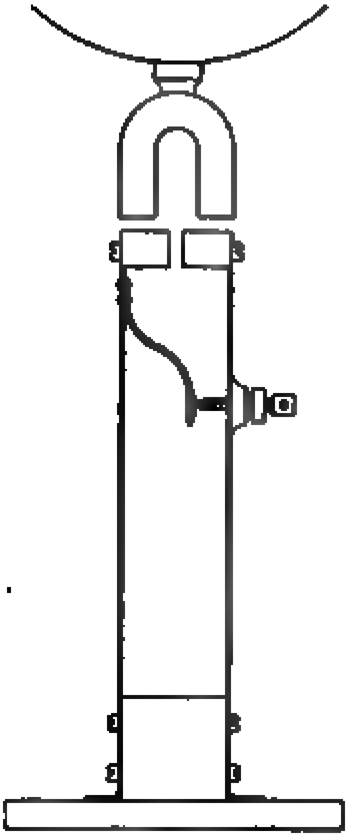


FIG. 202.—Two Forms of Contact Making Device.

time is the most uncertain, since even the most expensive stop watches have certain inherent defects and give results in practice that are not so reliable as the measurement of either watts or revolutions.

In the use of the relay, advantage is taken of the fact that all rotating standards are so designed that the register or dial begins to record at the beginning of an observation, and stops recording at the end of the period;

the record thus obtained being a correct indication of the actual energy passing through the meter during that period.

It is possible to fix the time at any given value, for while this necessitates R being a variable, the value of the latter may be accurately determined, since the dial may be read to 0.01 revolution, and all observations are taken with the dial hand at rest.

In a test the watts are determined in the usual manner by means of indicating instruments.

FIG. 203.—Diagram of Time Relay Operated Test Circuit.

The time is obtained from a **pendulum beating seconds,** either by means of an attachment placed on the escapement, or by a magnetic arrangement at the lower end of the pendulum rod. The escapement device is that used by the Western Union Telegraph Company for furnishing time to jewelers. Through a relay and a magnetically operated ratchet, a disk is caused to rotate one-sixtieth of a revolution once a second. A spring resting on the disk is in electrical contact with the disk thirty-six sixtieths of one revolution, or during thirty-six seconds. For commutator type watt-hour meters, this spring and disk are in series with the clutch circuit, and for induction watt-hour meters, the potential cir-

cuit, therefore, the watt-hour meter under test, in each case, records for exactly thirty-six seconds each minute, during which time readings are taken on the indicating instruments to determine the watts.

The formula now becomes—

$$\text{Watts} = \frac{3{,}600 \times K_h \times \text{Revs.}}{36}$$

$$= 100\ K_h \times \text{Revs.}$$

The value of S was set at 36 seconds, since in any arrangement of second pendulum and contact, it is difficult to so arrange the contact that the odd and even intervals of time are exactly of equal value. The sum of any two successive values will, however, be equal to two seconds and thus, by taking an even number of seconds, one source of error is eliminated. With 36, the factor $\frac{3{,}600}{S}$ reduces to a multiplying factor of 100.

Stop watches, which indicate seconds and fractions thereof, usually 0.2 or 0.1, are generally used for time measurement in tests conducted outside of the laboratory and in many instances in the laboratory itself. Their accuracy is determined by comparison with a standard pendulum or sweep second chronometer.

As **the accuracy of stop watches** is generally very much over-estimated, special care should be given in selecting one that will be reliable and accurate, and when used, it should be checked frequently at a number of points with a reliable standard, as the average watch is not always correct at all points of its dial.

The hand should be released and start to indicate the instant the key is pressed. With the second depression it should be immediately stopped, and on pressing the third time, it should return to zero. It should be noted that the hand does not " overthrow " during any of these operations.

As most watches indicate only in one-fifth seconds, an inherent error may occur, due to the starting and stopping, and this is of greater importance than its accuracy as a time piece.

While it is a poor watch that cannot be adjusted to keep time within one minute per week, or within one-hundredth of one per cent, still, many errors are liable to be introduced in timing the revolution of the rotating element of a watt-hour meter, and therefore only the best makes of watch obtainable should be used for this work, as those of the cheaper grades, due to imperfect design, construction and workmanship, may introduce serious errors in testing.

The balance wheel of the above type of watch completes its travel of approximately 250 degrees in one-fifth of a second. It is necessary, for good time keeping qualities, that its motion should be as free as possible, and that it should be entirely disconnected from the train for the greatest possible portion of this travel. It swings entirely free for approximately 240 degrees, and unlocks the escapement for 10 degrees, during which time the train drives the hand forward one-fifth of a second division and again locks it from any movement during the next 240 degrees

FIG. 204.—Wheatstone Bridge, Double Pattern. Wolff.

of the balance wheel travel. In other words, the hands of a watch are absolutely stationary during 95 per cent of any interval of time, and it makes no difference in the movement of the stop watch hand whether it is thrown in mesh at the beginning or the end of a travel of the balance. Therefore, with a perfect time piece, a perfect stop mechanism and absolutely no error on the part of the observer, an error of practically one beat, or $\frac{1}{5}$ second may easily occur in measuring time. In 30-second observations, this error may amount to $\frac{2}{3}$ per cent. When adding to this error those due to imperfect stop mechanisms, a throw of the hand in the interval between freeing it from the friction clamp and meshing it with the train, a similar throw in disconnecting from mesh and again clamp-

ing it, and the inaccuracy of the meshing itself, it is not difficult to realize that an additional error of ⅛ per cent or more may be introduced.

It is important that readings covering a period of at least 60 seconds be taken if accurate results are to be expected. The use of a watch beating $\frac{1}{10}$ seconds is recommended, as the error would only be one-half as great as when one beating $\frac{1}{5}$ seconds is used.

A Wheatstone bridge is an apparatus for measuring the ohmic resistance of conductors. It comprises a number of resistances having a low temperature coefficient. These resistances are wound on metal or wooden spools. The leads are attached to brass contact blocks, which

FIG. 205.—Wheatstone Bridge, with Decade Arrangement of Coils. Leeds & Northrup.

are mounted on a hard rubber plate. The resistances are cut in or out of circuit by means of plugs, or dial switches. Accessory to the apparatus are batteries for supplying the test current, a galvanometer, and contact keys for closing the battery and galvanometer circuits.

The bridge may have continuously variable ratio arms and one or more fixed comparison resistances, or it may have fixed ratio arms and a variable rheostat as the comparison resistance. In the measurement of resistances less than 1 ohm the Kelvin double bridge should be used; the apparatus provided for this work is usually a double set of similar atio arms, together with a low resistance standard (Fig. 204). The ostat arm of a Wheatstone bridge, and rheostats in general, may con- of a simple series of coils short circuited by plugs, or of any one of

several decade arrangements (Fig. 205). The decade arrangement consists of groups of equal decimal steps. They are easier and quicker to manipulate and involve fewer contact resistances. They are adaptable either to plug or switch connections.

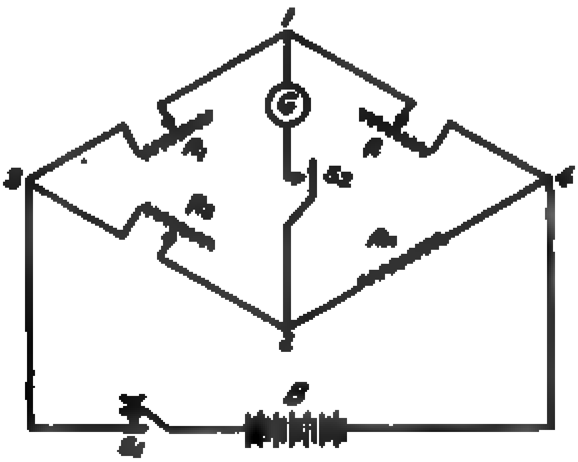


FIG. 206.—Wheatstone Bridge, Theoretical Connections.

The ratio arms of a Wheatstone bridge should be reversible. The connecting resistance to the branch points of the bridge (galvanometer or battery connection points) must be low, and should not exceed 0.0002 ohm, if ratio coils as small as 1 ohm be used. There should be not more than two contact resistances in a ratio

FIG. 207.—Double Contact Key.

arm. In bridges of older design, the ratio coils are in series, and are thus more subject to plug troubles. For facility in calibration, auxiliary potential connections should be provided to the branch points, or terminal points of ratio arms. Connecting resistances in the bridge should always be made low, and the galvanometer and

battery should be introduced at such points that the connecting resistance is in series with the rheostat arm rather than the ratio arms or the resistance under measurement. In the use of a bridge, the ratio arms should be chosen which will give a large setting of the rheostat arms in order to obtain a high percentage accuracy of reading, provided that such a choice is consistent with sensibility.

FIG. 208.—Double Contact Key, Diagram of Connections.

Fig. 206 shows the theoretical connections: r, r_1 and r_2 are known resistances, and r_x is the resistance to be measured. When the relation of the resistances is such that the galvanometer G shows no deflection,

$$r_x = \frac{r_2}{r_1} r.$$

The battery switch S 1 should always be closed before the galvanometer switch S 2, in order to permit the current in the coils to reach a state of stability before the galvanometer is connected to the circuit.

The use of a double contact key such as is shown in Figs. 207 and 208

is a very satisfactory method of obtaining this result. The battery is wired to the top leaves of the key, and the galvanometer to the lower

FIG. 209.—Wheatstone Bridge, Post-Office Pattern. Wolff.

leaves. It is obvious that contact *B* will be closed before *G* when the key is depressed.

Several different types of Wheatstone bridges embodying the above

FIG. 210.—Wheatstone Bridge, Slide Wire Pattern. Gurley.

principles are available. In that known as the post-office form (Fig. 209), variations of resistance are produced by the use of conical short cir cuiting plugs, which, when placed between the contact blocks, short cir

cuit the resistance connected thereto. This type is employed for general work where neither very high nor very low resistances are to be measured.

The slide wire bridge shown in Figs. 210, 211 and 212 is very convenient to manipulate, but it is not so accurate as other types. In this form (Fig. 213), the ratio $\frac{r_2}{r_1}$ is varied by moving the sliding contact b along the wire *a c*. This wire forms the resistance $r_2 + r_1$.

FIG. 211—Wheatstone Bridge, Cary-Foster Type Leeds & Northrup.

The wire should be homogeneous and of uniform cross section, so that the resistance per unit length will be constant. If the resistance *r* is known

$$\frac{bc}{ab} = \frac{r_2}{r_1}.$$

That form known as **the dial pattern** (Fig. 214) is probably best for central station use. In this type the various resistances are connected to stops over which a switch arm travels. The positive contact afforded by the pressure of the switch upon the contact blocks renders this type of apparatus superior to that of the plug type as ordinarily constructed.

The tops of the bridges should be kept scrupulously clean. Where the adjustment is made by plugs, the plugs are made to fit the taper holes as closely as possible, in order that the plug resistance may a minimum. Therefore, when using a bridge, the plug should

Fig 212.—Coil Holder for Carey-Foster Bridge. Gurley.

not be forced into the hole and twisted, as this only serves to destroy the fitting of the plug by wearing away the brass, which, falling between the blocks, is liable to reduce the apparent resistance

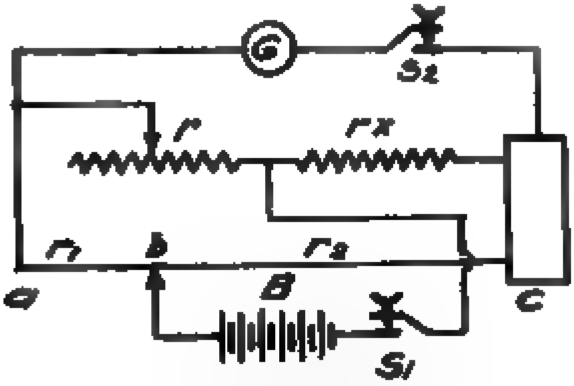


Fig. 213.—Wheatstone Bridge, Diagram of Slide Wire Pattern

of the coil by short circuiting it, and at the same time greatly increasing the plug resistance as a whole. Place the plug in the hole squarely and firmly, then lock it by a slight twist.

The metal parts of the bridge top or the plugs should not be handled, as the grease from the fingers can increase the plug resistance to twenty times the original value. The spaces between the blocks should be frequently cleaned by drawing a clean cloth between them, care being taken to force a sufficient amount of it down between them to fill up the space made by undercutting the blocks where they join the rubber top.

The sensibility of a bridge should not be increased by using too many batteries, as the heating of the bridge coils will result in large

FIG 214.—Wheatstone Bridge, Dial Pattern Leeds & Northrup.

errors produced by thermal currents. Two dry cells will give good results for most purposes up to 2,000 or 3,000 ohms, beyond which three, or at most four, cells may be used

A frequency meter, or indicator, is an instrument used for determining the number of complete cycles per second of an alternating current.

One type of indicator is based on **the resonance or tuned reed principle.** In construction, it consists of a pendulum, or reed, of given length, which responds to periodic forces having the same natural period as itself The instrument comprises a number of reeds of different lengths, mounted in a row, and all simultaneously subjected to the oscillatory attraction of an electromagnet excited by

the supply circuit being measured. The reed, which has the same natural time period as the current will vibrate, while the others will remain practically at rest (Fig 215).

The Westinghouse frequency indicator is based upon **the induction principle.** It consists of two voltage elements, one of which is connected to the circuit through an inductive resistance, and the other through a non-inductive resistance. The movable element consists of an aluminum disk which is pivoted so as to rotate between the air gaps of the voltage elements. The disk is irregularly shaped,

FIG 215.—Frequency Meter, Frahm Vibrating Reed Type Biddle

one half being circular in contour, and the other half slightly spiral. The disk is balanced so that it will come to rest in any position, and it is not subject to control by either gravity, or springs.

The torque of the element with which the non-inductive resistance is in series will increase with the frequency, and the torque of the element with which the inductive resistance is connected in series will decrease. Each element tends to move the disk in the opposite direction, and it will move in the direction of the weaker element until the difference of diameter within the influence of the two electromagnets is sufficient to equalize the torque of each, when the disk will stop, the indicator indicating the frequency on the scale.

As **an instrument for laboratory use,** the resonance pattern possesses many advantages over those which operate on the induction principle. Most portable instruments of this type are provided with a satisfactory means of regulating the amplitude of the vibration to the voltage of the circuit, thus providing an instrument whose accuracy is independent of voltage.

The accuracy of a frequency indicator may be checked by taking the speed of the generator with a tachometer or ordinary speed counter, and using the formula

$$\text{Cycles per sec.} = \frac{\text{Rev. per min.} \times \text{poles}}{120}.$$

A power-factor meter is an instrument which indicates directly the power-factor of an alternating current circuit. Its indicator moves over a graduated dial, so marked as to give the actual or true power in a percentage of the apparent power.

In the Westinghouse **single-phase power-factor meter,** the fixed elements consist of three stationary coils, and the movable element comprises an iron armature, to the shaft of which an indicator is attached. The shaft is pivoted and mounted on jewel bearings. The movable system is balanced and not subjected to spring or gravity control. Two of the stationary coils are connected to the supply circuit in a split phase relation through an inductive and a non-inductive resistance, so that, when the current in one coil is at a maximum, the current in the other will be zero. A rotating field is thus produced, which moves at a speed proportional to the frequency of the supply circuit. The armature is magnetized by the third coil which is in series with the circuit, and, as the coil is non-inductive, the magnetzing current in the armature is in phase with the voltage of the circuit.

Under the influence of current the armature takes a position in which its zero field will occur at the same time as the zero of the rotary field. The difference in degrees between the phases of the two currents are indicated by means of the indicator and a suitable scale.

Two and three-phase power-factor meters, based upon the above principle, are available. All single-phase instruments have current coils wound for 5 amperes. Two or more current transformers are required with polyphase meters, including those of 5 amperes capacity. To attain the highest accuracy the series current should be between 3 and 5 amperes, and the potential within 25 per cent of normal. Poly-

phase meters are not satisfactory on circuits which are unbalanced to the extent of 20 per cent or more.

An oscillograph is sometimes used in the laboratory to record graphically the waves of current and potential, under various conditions, and for studying the relations of values and phase angles existing between them (Fig. 216).

Handling of Instruments with Relation to their Accuracy.

Potentiometers, standard cells, standard resistances, and current and voltage transformers used in connection with secondary stand-

FIG. 216.—Oscillograph. General Electric Company.

ards, should have their constants determined by some reliable testing authority other than the manufacturer, prior to being placed in service in the central station laboratory. **Certificates of accuracy** from reliable independent testing authorities are desirable in the case of secondary standards, though not absolutely necessary.

The fees established by the National Bureau of Standards for tests of resistance standards, potentiometers, standard cells, Wheatstone bridges, and current and voltage transformers, are given in the following tables. Full information concerning tests on these and other types of electrical instruments is contained in circulars issued by the Bureau, and supplied to interested persons upon request.

RESISTANCE STANDARDS FOR CURRENT MEASUREMENT

ACCURACY, 0.01 PER CENT

Denomination		I	II	III	
(a) 1.0	ohm	$2.50	$2.00	3 amp.,	$1.00
(b) 0.1	"	2.50	2.00	15 "	1.25
(c) 0.01	"	3.00	2.00	100 "	1.50
(d) 0.001	"	3.50	2.00	500 "	1.75
(e) 0.0001	"	4.00	2.00	1000 "	2.00

(f) For standards having values 2, 3, 4, or 5 times any of the above, the fees will be 40 per cent additional.

I. Measurement at room temperature with low test current.

"Low test current" signifies a test current so small as to produce no appreciable heating of the standard.

II. For measurement at an additional temperature.

III. For an additional measurement with test current not exceeding the values given in the table.

PRECISION RESISTANCE APPARATUS

ACCURACY (IN GENERAL), 0.01 PER CENT

(a) Minimum fee for each piece of apparatus..........	$3.00
(b) Rheostats, bridges (excepting ratio coils), potentiometers (excepting coils for reducing range), etc., per coil	.25
(c) Ratio coil of bridges, per coil..........	.50
(d) Calibration of slide wire, per section..........	.25
(e) Reduction factors for potentiometers, per factor......	2.00
(f) Cleaning contacts, per contact..........	.10

VOLT BOXES. FACTORS

(g) Test with low voltage, per factor..........	$1.50
Test with service voltage (not exceeding 150 volts).	
(h) Factors 2, 3, 5, or 10, each..........	2.00
(i) Factors 20, 30, 50, or 100, each..........	3.00

STANDARD CELLS

ACCURACY, 0.0001 VOLT

(a) Testing standard cells at one temperature, about 25° C., $2.00

CURRENT TRANSFORMERS

Test for ratio of transformation (quotient of primary or line current divided by secondary or meter current) with a given load of instruments (or specified resistance and reactance) connected to the secondary, at five values of primary current, viz., 10 per cent, 20 per cent. 40 per cent, 60 per cent, and full load, unless otherwise ordered; secondary full load current not exceeding 10 amperes:

(a) Primary current not exceeding 50 amperes, tested at one frequency, using currents of approximately sine wave form	$3.00
(b) Exceeding 50 amperes and not exceeding 250 amperes, tested as above	4.00
(c) Exceeding 250 amperes and not exceeding 500 amperes, tested as above	5.00
(d) Exceeding 500 amperes and not exceeding 1,000 amperes, tested as above	8.00

(e) Each additional current above five will be charged one-tenth of the base fee.

(f) For each additional frequency at which a test is made at five currents, the additional fee will be one-half of the base fee.

(g) For each additional secondary load (of instruments, or specified resistance and reactance) at which a test at one frequency is to be made with five values of primary current, the additional fee will be one-half the base fee.

(h) For the determination of the phase angle between primary and secondary currents, in addition to the ratio, for five values of primary current as above, the additional fee will be one-half the base fee as given above.

(i)[1] Each additional transformer after the first, to be tested at the same time and through the same range,

[1] This one-half rate applies only to the regular test with five values of primary current; each additional current above five, for the additional transformer, will be charged one-tenth of the base fee as given in the schedules.

will be charged one-half of the base fee as given above.

VOLTAGE TRANSFORMERS

Test for ratio of transformation (quotient of primary or high-tension, applied voltage divided by secondary or low-tension, terminal voltage) with a given high-tension voltage, and five values of secondary load, namely, no load, 50 per cent, and full load, unity power-factor; 50 per cent and full volt-amperes [1] approximately 20 per cent power-factor, unless otherwise ordered.

(a) Primary voltage not exceeding 300 volts, tested at one frequency, using electromotive forces of approximately sine wave form	$3.00
(b) Exceeding 300 volts and not exceeding 750, tested as above	4.00
(c) Exceeding 750 volts and not exceeding 1,500, tested as above	5.00
(d) Exceeding 1,500 volts and not exceeding 3,000, tested as above	7.00
(e) Exceeding 3,000 volts and not exceeding 7,000, tested as above	10.00
(f) Exceeding 7,000 volts and not exceeding 12,000, tested as above	15.00
(g) Exceeding 12,000 volts and not exceeding 17,000, tested as above	20.00

(h) For each additional frequency at which a test is made at five loads, the additional fee will be one-half the base fee.

(i)[2] Each additional load above five will be charged one-tenth of the base fee.

(j) For each additional primary voltage at which a test at one frequency is to be made with five values of secondary load, the additional fee will be one-half the base fee.

(k) For the determination of the phase angle between primary and secondary voltages, in addition to the

[1] When the rated capacity of the transformer exceeds 25 watts, the test at 20 per cent power-factor will be made at 12.5 and 25 volt-amperes.

[2] These fees are based on a moderate range of frequency. Tests at extreme frequencies will be subject to a special extra charge, and should always be arranged for in advance of shipment of the apparatus.

ratio, for five values of secondary load as above, the additional fee will be one-half the base fee as given above.

(l)[1] Each additional transformer after the first, to be tested at the same time and through the same range, will be charged one-half of the above fees.

Instrument Maintenance.

In addition to the check when an instrument is purchased, standard cells, standard resistances, potentiometers and transformers should be tested if anything in their performance raises a doubt as to the accuracy of the results being obtained.

The best results in **instrument maintenance** are obtained where the testing is done in a systematic manner, and with careful attention to detail.

The standard cells should be intercompared weekly, and at least one of them should be sent semi-annually to a standardizing laboratory for verification. The working standard resistances should be checked against the reference standard resistances at least semi-annually, but, whenever a standard resistance is suspected of having received an overload of current, or has been subjected to mechanical injury, it should be checked immediately.

Two standard resistances of the same nominal value can be compared by putting them in series, passing a constant current through them, and measuring in quick succession the fall of potential across each, using a potentiometer and a throw-over switch. The reference standards of resistance should be verified by a standardizing laboratory at least once every two years.

The various coils of the potentiometer should be checked against each other at least once a year, and the volt box should be checked at least once each month. The ratios of the resistances of the various steps in the volt box may be determined by passing a constant current through all of the coils, and measuring the fall of potential across each step by means of the potentiometer. Care must be taken not to exceed the capacity of the potentiometer. Where a standard resistance of one thousand ohms or so is available, the coils of the volt box may be checked by direct comparison with it in the manner indicated above.

[1] This one-half rate applies only to the regular test with five values of secondary load; each additional secondary load above five, for the additional transformer will be charged one-tenth of the base fee as given in the schedules.

Measurements with an accurate Wheatstone bridge will detect errors in ratio which are in excess of 0.1 per cent.

Instruments employed as secondary standards should be set up permanently and placed in the care of a competent instrument man, who should be held responsible for their accuracy.

The secondary standards should be compared with the primary standards at least once every two weeks. The comparison should consist of a verification of the zero and a check at one point above half scale on every range of the instrument. A complete check throughout the working range should be made at least every three months and in addition, whenever an appreciable change is found between the results of successive bi-weekly checks.

All indicating instruments used as working standards should be checked at least once every two weeks. Each check should consist of the verification of the zero and a check at any point between two-thirds and full scale. Once every two months, a complete check at all cardinal points should be made, and the results plotted on a calibration curve which should accompany the instrument.

When the weekly check indicates a deviation greater than 0.5 per cent from the previous calibration, or an error of 1 per cent in its indication, the instrument should be repaired and recalibrated.

Indicating instruments used in outside testing, or in testing watt-hour meters in the laboratory, should be checked directly against the secondary standards. **Checks of calibrated resistances** should consist of a determination of the current taken by each unit at the normal voltage of the system, and should be made weekly. Checks of rotating standards used in making service tests should be made at sufficiently frequent intervals to insure that the variations of their accuracy do not exceed the tolerated tesing errors in making service tests of watt-hour meters.

All checks should be recorded.

Any piece of apparatus showing an excessive variation between successive tests should be subjected to a special investigation to ascertain the cause. If the cause of the variation cannot be removed, the apparatus should be abandoned.

Stop watches should be checked daily by comparison with the master standard of time.

The use of corrections to working instruments may be avoided by maintaining the instruments practically correct at all points throughout the range in which they are used. For a working instrument to be considered practically correct, its error should not exceed the value given below:

Indicating instruments	+ or — 0.3%
Rotating standards	+ or — 0.5%
Stop watches (approximately 0.1 sec. in 30 sec.)...	+ or — 0.3%
Standard resistances	+ or — 0.3%

Where it is not convenient to maintain the instruments within the above limits, correction curves or tables should be made to accompany the instruments, giving the value of the correction to be applied at frequent points on the scale.

New correction curves should be made whenever, in the periodic checks, a change is found from the previous curve.

Corrections should be reported only to a degree of accuracy corresponding to that with which the scale of the instrument may be read.

The form used for the correction certificates should be designed

SCALE CORRECTION FOR INST. NO..................

. Divisio

High ubtract

Low do

. Division

Date . .. ..191 By ....

FIG. 217.—Form for Instrument Correction Curve.

with a view to ease in use and the avoidance of confusion as to the sign of the correction. The accompanying form is recommended for this purpose (Fig. 217).

Indicating instruments are best **calibrated** by connecting them in circuit with secondary standards, obtaining a given deflection on the instrument under test, and determining the corresponding true value by means of the standards. The correction to be applied to the instrument reading is then determined by reference to the corrected indication of the standard. In the case of instruments of the electrodynamometer type, which may be calibrated on continuous current, readings reversing the direction of the voltage and current through the instrument should be taken to eliminate the effect of the earth's field. The true value is the average of the direct and reversed readings.

Where only a small number of instruments are to be checked

they may be compared directly with a potentiometer, thus doing away with the secondary standard instruments and reducing the opportunity for error. The best forms of modern potentiometers are quick and convenient in operation, and the additional time consumed will be small.

Where a Wheatstone bridge is available, **measurements should be made of the resistance of voltmeters, potential circuits of wattmeters, multipliers,** etc., at the time these instruments are received from the maker. These values should be recorded and when instruments are brought in later for check the resistance measurements should be repeated. Often a defective contact in a key or a loose wire connection will be found by the bridge measurement before the trouble becomes great enough to be detected in service.

The **accuracy of rotating standards** is determined by comparison with indicating instruments. The same methods may be used for testing watt-hour meters in service. Under laboratory conditions, however, where steady loads and better general conditions are obtained, the accuracy of the test should be much greater than in corresponding tests on meters in service.

Rotating standards should be checked in the same manner as they are used; that is, starting and stopping them at the beginning and end of a definite period of time, by means of a switch in the potential circuit.

In cases where the Philadelphia Electric method of testing is used, the standards should be run continuously, and the number of revolutions timed. Where the standard is started and stopped, a special device for automatically closing the starting circuit for a predetermined time is advantageous. One form of apparatus for this purpose is illustrated in Fig. 203. Rotating standards should be tested on one combination at least once a week. A test should be made monthly on each of different currents and potential coils. Care should be taken to test alternating current standards on the same wave form as that impressed on the system. A quite different wave form might be obtained from a motor generator used for testing purposes than is impressed upon a system. The standard should not deviate from 100 per cent more than 0.5 per cent. If it does, the error should be known and proper correction applied.

Polyphase indicating wattmeters and rotating standards should be investigated for the **effect of interference between the elements.** Where the difference between the accuracy of the instruments as checked on single-phase and the accuracy as checked on polyphase does not exceed 0.5 per cent, **the standards may be calibrated on a**

single-phase circuit. If the difference between the accuracies on single-phase and polyphase exceeds 0.5 per cent at any point in the working range, the standards should be calibrated with a polyphase load of the same number of phases as that on which they are used in service. The secondary standards used should consist of two single-phase indicating wattmeters, one corresponding to each element of the polyphase standard.

Where the "phase rotation" or order of the phases in service differs from that employed in test, an interference error may occur even when the standards are calibrated on a polyphase load. The effect should, therefore, be investigated, and the standards, showing a difference of more than 0.5 per cent when the phases are interchanged, should be discarded.

Calibrated resistances are checked on continuous current by connecting in series with a standard ammeter, and measuring the current taken at the normal voltage of the system.

If a voltmeter is connected directly across the resistance, its current passes through the ammeter and should be corrected for. When the combined drop in the ammeter and in the leads connecting between it and the calibrated resistance does not exceed 0.1 per cent of the line voltage, the voltmeter current may be eliminated by connecting the voltmeter back of the ammeter. Calibrated resistances for alternating current testing must—unless they are strictly non-inductive—be checked on alternating current of the proper frequency against a standard wattmeter.

Sources of Error.

An important matter in connection with the use of electrical instruments is the question of the **sources of error** and the best means of securing a required degree of accuracy from a given set of instruments. It may be stated that, in many cases, the user underestimates the error and overestimates the accuracy of the result. Portable instruments are sometimes used in places, subject to strong stray fields or extreme temperatures; subsequent comparison with standards in the laboratory may show that the working instruments have small errors, while their performance under the unfavorable conditions may have been in error to the extent of 5 per cent or more.

Under the head of **inherent errors** may be noted those **due to** the effect of change of **temperature.**

In continuous current indicating instruments, the temperature coefficient of the voltmeter is a summation effect of the temperature

coefficients, of the strength of the magnets and springs, and the resistance of the coils. In ammeters, there is the added effect of the change in resistance of the shunts. In voltmeters, the principal changes are those due to the magnets and springs, since the resistance in series with the movable coil is of negligible temperature coefficient. The springs have a negative temperature coefficient of about 0.04 per cent per degree C.; that is, they are weaker at higher temperatures. The temperature coefficient of the magnets may be plus or minus; but it is usually of the same order and sign as that of the springs, that is to say, the magnetic field is weaker at higher temperatures.

Ammeters usually have a much larger temperature coefficient than voltmeters. This is due largely to the millivoltmeters, which have a low resistance, a considerable proportion of which is copper. Consequently they have a high temperature coefficient. It is not feasible to wind the moving coil with manganin wire as the resistance would be too high to work on the available millivolt drop of the shunts unless the design were so changed that more wire could be wound upon it. While it could be made to work in this way, the movable element would be too heavy for good performance. The temperature coefficient may be greatly reduced by using larger shunts, giving a higher drop, say 200 millivolts; this allows the use of manganin wire in series with the copper coil.

In connection with the question of temperature errors of millivoltmeters, that due to heating of the shunts is very important. In addition to changes in resistance due to temperature variation, thermoelectric effects may produce considerable error.

Errors due to thermoelectric effect may be observed by passing current through the shunt until it has assumed working temperature; upon opening the circuit, the millivoltmeter will indicate a small current.

This effect will be produced by any condition which occasions unequal heating of the ends of the shunt, such as a bad contact at one end or a difference in the size of the conductors connected to the shunt.

In the electromagnetic (soft-iron) ammeter, with spring control, an increase of temperature lowers the permeability of the iron, but also reduces the strength of the spring in nearly the same amount; hence these ammeters are very nearly independent of ordinary temperature changes. In the electrodynamometer instrument, the only element of importance, in respect to temperature coefficient, is the controlling spring; as there is nothing of any consequence to bal-

ance it, such instruments will read too low at temperatures below that at which they are correct, the temperature correction being about 0.04 per cent per degree C. This assumes that potential circuits contain so small a percentage of copper that their change of resistance with temperature does not sensibly affect the result. For ordinary voltage ranges this is the case.

In the soft-iron voltmeter the temperature coefficient depends mainly upon the ratio of the resistance of the copper coil to the total resistance of the instrument. This ratio is a question of design, depending upon the range of the instrument and the amount of power spent in it. The temperature coefficient of well-made voltmeters of this type, for the usual commercial voltages, is quite small, and for practical work need not be taken into account, except in extreme cases.

In the commutator type of rotating standards, temperature effects are of great importance. The disk being of aluminum has a large temperature coefficient of resistance and means must be provided to compensate for the resultant variations in drag.

In a standard, whose potential circuit has a temperature coefficient equal to that in the disk, the effects of variations in room temperature are eliminated, since the temperature coefficient of the potential circuit compensates for the temperature coefficient of the disk. The potential circuit is, however, heated by the current passing through it and therefore will not come to a constant temperature until voltage has been applied for some time. Any test made before the potential circuit has reached a constant temperature will be in error. In the types of standards in use at present, the time required is about 20 minutes at normal voltage.

To save time, the heating of the potential circuit may be hastened on three-wire circuits by applying double voltage for a shorter period of time. This period should be definitely determined for each type of standard, since, if it is exceeded, overheating will occur, resulting in an error in the opposite direction.

Some types of rotating standards have connections whereby the voltage circuit is split in two parts, which are connected in parallel on normal voltage, so that the equivalent of double voltage heating may be obtained on a two-wire circuit.

Where the time between successive tests in service is so short that the voltage coil does not in the meantime cool to the temperature of the rest of the standard, overheating may result from applying double voltage for the full time, and it is advisable in such cases to reduce the time of heating.

Induction rotating standards are practically free from heating effects.

Errors due to changes of room temperatures are usually only temporary, unless the instrument has been subjected to very abnormal temperatures. Another source of error is **change with time and use.** Permanent magnets of the best makes will occasionally show changes with time. When the instrument is new, the magnet may increase in strength; later it is more likely to decrease. Controlling springs also show slight changes with time. If magnet and springs weaken to the same extent in a continuous current instrument, the accuracy is unaffected. Where continuous current instruments are used in the neighborhood of dynamos or motors, or in other locations subject to strong **stray field** (for example, near heavy conductors), their indications will be considerably affected at the time of the use, and in addition, permanent change of the magnets may occur. Switchboard instruments are liable to exposure to stray fields, and should be shielded against them. The iron case very generally used for such instruments affords considerable protection, but in addition, it is best to keep heavy currents well away from the instruments, and as a further precaution, important instruments (watt-hour meters and voltmeters, for example) should be checked in position, under working conditions. Care must be taken that the portable instruments used in this checking are in a location not exposed to stray fields; if this is impossible, the mean of two readings should be taken; for the second reading the instrument is turned 180 degrees from its first position.

Continuous current rotating standards are affected in a manner similar to continuous current instruments. They should be always set up with the plane of their current coils parallel to the line of force of the stray fields.

Alternating current rotating standards of the induction type are very little affected by stray fields, since only alternating fields at the same frequency of the circuit can affect these instruments.

Under the head of **inherent errors of a mechanical nature** may be mentioned the friction of pivots, defective performance of springs, error of marking the scale, and lack of balance of the moving coil. The friction of pivots should not be noticeable in a good instrument, unless it is old or has been roughly handled. Good performance in this respect requires not only good workmanship in the pivots and jewels, but also good design. It is evident that friction cannot be entirely done away with, and hence a spring should be provided which is strong enough to cause the coil to take up its proper posi-

tion within the error of reading the position of the indicator on the scale. It is desirable, in all electrical measuring instruments, to keep the ratio of torque to weight of movable element as high as possible. It should be noted that an instrument with a very high torque may really be a poor instrument, if the high torque is obtained by using an excessively heavy moving system.

Another source of error is that of **zero shift.** This is only temporary and gradually disappears. It is usually manifested in the case of indicating instruments under the following conditions: Suppose that the index stands exactly at zero with no current flowing, after a day or two of rest. If current or voltage be applied so as to give full scale deflection, and this is maintained for a short time only, the indicator will usually return to zero within the limit of reading. If full scale deflection is maintained for an hour, it is quite likely that on breaking the circuit, the indicator will not return exactly to zero; if the full scale deflection lasts several hours, the discrepancy will be still greater.

The amount of this shift varies in different classes of instruments, and in different individuals of the same class. In first-class voltmeters it should be just noticeable; in millivoltmeters, as a rule, it is considerably greater, although occasionally a millivoltmeter will show a very good performance in this respect. The effect of zero shift upon the reading is greatest when an instrument is used for a small deflection after it has sustained a large deflection for a considerable time. The reason for the poorer performance of millivoltmeters lies in the necessity of using springs which approach pure copper in electrical qualities; this causes the mechanical properties also to approach those of copper. For the voltmeters no such limitation exists, and the springs are usually of bronze which has the most suitable mechanical qualities, regardless of its specific resistance.

The zero performance of a spring depends on its design as well; it is evident that there is an elastic limit for any spring, and that the thickness and length of the spring will determine this limit for springs of a given material.

It has often been assumed that the torque of a spiral spring is exactly proportional to the angle of twist; hence in testing instruments such as the Siemens dynamometer, the "constant" of the instrument was determined for one value of current, and assumed to hold for any other value; or it was taken as the mean of several determinations with different currents. This assumption is incorrect, and may lead to errors of 1 per cent or more. In the ordinary direct reading instrument this variation does not appear if the scale is properly graduated. However, if by accident the spring should be thrown out of its original shape,

the scale will not longer be correct, even though by shifting the spring holder the indicator be brought back to zero.

The question of **zero errors** and how to correct them is of frequent occurrence. Sooner or later the indicator of nearly every meter fails to indicate zero at zero load. The exact reason is not always apparent. It may be known that the error appeared immediately after a short circuit or after the meter was dropped to the floor, but that information would not show whether the spring had changed its shape, the indicator had been bent, some part of the movement slipped, or one or more of a number of other possible disarrangements had happened. A rather common source of error at zero as well as at other readings is a fine springy piece of lint resting on a fixed part and pressing lightly against the movable part in such a way as to cause friction by acting as a little additional spring.

To add, algebraically, the zero error to the observed reading seldom gives exactly correct results. Sometimes it introduces a greater error than if no correction had been attempted.

In many instances where the zero reading has changed quite appreciably, there is no difference in the calibration of the instrument at points above one-fourth scale reading. There rarely is a uniform change throughout the scale. As a general thing, it is safer to reset the zero reading or to assume that the zero error has not changed the calibration at the upper part of the scale than to attempt to correct for it. Indiscriminate resetting of the zero reading by means of the usual spring-adjustment is not to be recommended. If the error has been caused by bending the indicator it is better to bend it back again, even though the displacement was slight. If this is not done the relative positions of the fixed and movable elements of the meter will not be the same for any given reading as they were when it was first calibrated. The effect of this is most noticeable in those instruments which are direct-reading and do not have uniform scales. When recalibrated, the readings on the scale will be found to follow no uniform law. The reading at one point may be too high and those a short distance on either side of it too low. Such irregularities make the correction of a set of instrument readings more laborious than it would be if all readings were a certain percentage high or low.

At one time **instrument scales** were engraved, or printed, on the assumption of a particular law; the instrument was then adjusted by trial to make it fit the scale as closely as possible. While this is probably done at the present time for instruments of lower grades, it is recognized that a good instrument should have a scale gradu-

ated to fit it. It is not necessary, of course, to determine every scale division by test, especially in continuous current instruments with nearly uniform scales. It is usually considered sufficient to determine say ten or fifteen points by actual test; intermediate points are filled in, sometimes by hand, preferably by a mechanical method. While for ordinary purposes it is sufficient to check an instrument at say, five points, for the most careful work this is not sufficient, and points much closer together should be taken. The simple removal and replacement of the pole pieces of a continuous current instrument—in fact, even the tightening of the screws that hold the pole pieces—will affect the distribution of the magnetic flux so that a scale which fitted the instrument before the operation will show appreciable errors thereafter. It may be seen from this, and the fact above noted in regard to deformations of the spring, that any mechanical change, adjustment, or accident to an instrument should be followed by a test. As to initial **accuracy of scale,** some makers claim to make their portable continuous current instruments correct to within 0.1 division. It is probable that this represents the limit of possible accuracy of the scale when the greatest care is taken. No such accuracy is attained in the average product.

Another mechanical source of error is the imperfect **balancing of the movable system.** This may be detected by holding the instrument in various positions, with no current flowing through it. A portable continuous current voltmeter examined in this way will show a change of zero reading of not more than a few tenths of a scale division if in good balance; millivoltmeters, wattmeters, and alternating current instruments, all of which usually have a smaller ratio of torque to weight than the continuous current voltmeter, may show as much as one division. If an instrument shows considerable variation of zero reading, when examined as above, care should be taken to have it on a level support when in use as well as when it is tested. At a convenient opportunity the instrument should be put in order.

The preceding errors are inherent in the instrument; another and important class may be designated as **external errors, or errors due to the method of use.** Assuming that an instrument is well designed, and has no errors due to heating produced by the current, it is still possible for errors to occur. One of the most common causes is the stray field from other instruments, from conductors carrying heavy currents, or from dynamos or motors; even nonmagnetized masses of iron may affect the flux in the instrument. If possible, it is well to avoid using the instruments in exposed loca-

tions; if circumstances compel the making of tests in places subject to strong stray field, the instrument may be read, then quickly turned 180 degrees and read again; by repeating this process several times an idea may be had of the extent of which the instrument reading is affected. The effect of stray field depends on the nature of the field and the design of the instrument. Consider the case of a stray field due to a heavy continuous current; in this field is a continuous current instrument of the permanent magnet, moving coil type. The effect of the stray field is to change the strength of the field in which the coil moves; the distribution of this latter field is not perceptibly changed. Hence if the amount of the error is determined as above, it may be allowed for by a percentage correction for readings on any part of the scale so long as the disturbing stray field is constant in amount and direction.

With other forms of instrument the case is quite different. Take the case of an electrodynamometer voltmeter, as used for alternating current, and assume the usual case of the moving coil turning through approximately 90 degrees for full-scale deflection. A position of the instrument can be found such that the stray field produces no effect for a given position of the moving coil and there is no torque between it and the stray field. As the coil moves out of this position, an increasing effect of the stray field may be noted. With even a weak field, such as that due to the earth, the effect on an instrument of this type is quite appreciable, and the usual method of avoiding error in the test of such instruments consists in measuring with standard instruments the current, voltage, or power required to bring the indicator of the instrument under test to a given point on the scale. The direction of current is now reversed and a second measurement made, with the same reading of the instrument under test. As the effect of the earth's field is of the order of 1 or 2 per cent of the maximum scale reading, the arithmetic mean of the two values read from the standard instruments will give the value which would be found with no external field. When such an instrument is used on alternating current circuits, stray fields such as the earth's, which do not change in direction, have no effect on the reading. Here the trouble is likely to come from heavy alternating currents of the same (or nearly the same) frequency as those in the instrument. This may be avoided to a large extent by running all leads as non-inductively as possible, avoiding loops. If other sources of stray alternating flux exist, such as transformers, the instrument may be turned through 180 degrees and the effect

noted. Here also it may be possible to find a position of the coil such that the stray field exerts no torque upon the coil.

Stray alternating fields, if not too strong, should have no effect on a permanent magnet type of instrument. If the strength of field exceeds a certain value, the effect will be to partially demagnetize the magnet, making the instrument read low at the time and thereafter until repaired.

Some instruments of the electrodynamometer type are made astatic, in order to avoid error due to stray field. This is accomplished by having two movable coils so connected that a stray field, if uniform, produces equal and opposing torques on the two (Fig. 147). If the stray field has the same value at the two coils, no error is produced. It is not safe, however, to assume that such instruments may be used without error in close proximity to heavy currents, as theory and experiment show that appreciable errors may result. With astatic instruments the same precautions should be taken as for the ordinary form. The results obtained will of course be more reliable.

Another **source of error** is that **due to electrostatic action** between the moving part of the instrument and some fixed part. Rubbing the cover glass over the indicator will often cause the indicator to move from its proper zero position, due to the action of an electric charge produced on the glass. The remedy for this consists in breathing on the glass, the moisture causing the charge to disappear. A similar effect has been noted when calibrating wattmeters by the method of separate sources of current and voltage. When the potential of the fixed coil is appreciably different from that of the moving coil, an electrostatic force is exerted between the two which may introduce errors into the readings. The remedy is to arrange the circuits so that the fixed coil and the moving coil may be joined together at one point. This requires care to avoid trouble due to contact between the circuits at some other point.

The **error of reading** depends partly upon the construction of the instrument, partly on the skill of the observer. Where accurate readings must be taken, it is the general custom to use an indicator with a flattened end, in connection with a mirror, to avoid parallax (Fig. 183). With a well-made continuous current instrument of this sort, it is possible for a skilled observer to make a reading anywhere on the scale to about 0.1 division on the usual scale. This refers to the case of steady current or voltage; on commercial circuits, where considerable fluctuations occur, the error of reading will of course be greater.

The percentage of **error of reading of any instrument** varies with the deflection of the instrument, being smaller, the larger the deflection. For example, an instrument has a scale of 100 equal divisions, which can be read to one-tenth of a division. The reading error at full scale is then 0.1 per cent, and at scale division 10 it is one per cent (assuming a uniform scale). This emphasizes the necessity of selecting such instruments in a test that the readings are well up the scale.

An important error to be avoided in reading is that due to parallax, that is, the dependence of the apparent position of the indicator on the angle at which the observer views the scale. Indicating instruments of the best types are provided with a strip of mirror along the edge of the scale under the indicator (Fig. 183). When the eye is in such a position that the reflection of the indicator appears to be behind the indicator, the line of sight is perpendicular to the plane of the scale, and the reading obtained represents the true position of the indicator.

Parallax errors are also of importance in stop watches, the second hand of which sometimes does not lie close to the dial face. An error of 0.1 second, approximately, equivalent to 0.3 per cent in a 30-seconds reading is easily made and larger errors may result from carelessness. Care should be taken to view the hand in a direction perpendicular to the dial face. The reading may be checked by first holding the watch with the hand pointing toward the observer and repeating the reading with the hand pointing away from the observer.

In addition to the **errors** noted **in** connection with **rotating standards** is also that **due to inertia of moving element** in starting and stopping. These errors occur in the potential switch method, **but** are absent in a method where continuous rotation is used. It **has** been discovered that the loss in revolutions in starting is generally greater than the gain in stopping, but this error is small enough to be negligible in commercial meter testing.

In stop watches, the following are **inherent sources in error.**

When starting the second hand, in some stop watches, it will be found that the hand is either sluggish, or that it jumps ahead or back. This error can be detected by observation or by checking against a pendulum for 4 or 5 seconds.

If the second hand is out of center, there will be an error if stopped on certain portions of the scale, while for a complete revolution, the watch will be accurate. Such a stop watch, if used, should be checked at several points on the scale and errors ascertained and allowed for in the calculations.

If the scale is not uniformly divided, the errors will be similar to

those mentioned under second hand out of center and should be handled accordingly.

If a stop watch does not keep good time, the per cent error can be figured by ascertaining error in minutes for a 24-hour run and dividing this by 1,440 (the number of minutes in a day).

In the case of **calibrated resistances,** if the resistance material has an appreciable temperature coefficient, **errors due to change in temperature** caused by the flow of current might be considerable and indeterminate, due to the fact that the temperature would be difficult to measure.

The constant heating and cooling of the resistance material is also liable to cause changes in the resistance. Then, too, as the leads are considered part of the resistance, a fault in these may introduce serious errors.

If calibrated resistances are to be used for alternating current testing, they must be non-inductively wound, otherwise the wattages corresponding to the voltmeter readings will be low.

The matter of **good electrical contact** is an important one in connection with the use of electrical instruments. One case in particular is that of the continuous current millivoltmeter used with separate shunts as an ammeter. The millivoltmeter is connected to the shunt by two leads, and in most instruments now in use this involves four contacts in the instrument's circuit, two at the shunt and two at the instrument binding posts. As the resistance of the instrument is only a few ohms, a corroded or dirty terminal or binding post surface may introduce errors which amount to several per cent. In a voltmeter of the usual 150 volt range this additional resistance would occasion no appreciable error.

Precautions.

Electrical standards, in general, are of delicate construction, liable to disarrangement from excessive vibration or jars, and should, therefore, **be handled with extreme care.**

In setting up the apparatus for test the standards should be located with due attention to sufficient light, convenience and comfort in reading, steadiness of support, leveling, avoidance of extremes of temperature, the influence of external magnetic fields and vibration.

In addition to the rules which are given in the following clauses, there are certain particular **precautions** which should be observed in using each make of instrument. The instructions furnished by makers should be carefully followed, and each type should be studied

to ascertain all its causes of error and corresponding precautions should be taken in its use.

In using electrical measuring instruments, and setting them up for test, there are a number of points to be considered which are often overlooked, even by those who are more or less familiar with instruments.

Modern instruments, as a class, are so designed and constructed that they will stand a great deal of service under severe conditions, if given proper care and guarded against abuse; and it is certain that the major portion of defects which arise in meters are the result of conditions which the user could have guarded against had he given the matter a little preliminary thought.

To compile a complete list of things to avoid, and other things which it is equally important to do—if instruments are to be handled properly and not subjected to abuse—is a difficult matter, and it is not possible in a condensed form to discuss all types of instruments and the conditions affording the most favorable operation of each.

The following list of precautions, however, if observed, will do much to prevent damage to instruments, resulting from improper connections, or errors due to the presence of external influences tending to affect their accuracy.

Handle instruments carefully.

When moving them around, be careful to lay them down gently to avoid damaging the fine points of the pivots or the polished surface of the jewels. A common practice which is very detrimental to the pivots and jewels of instruments, provided with separate carrying cases, is that of standing the case with the opening at the top and dropping the meter in. The proper way is, to lay the case on its side and slide the meter in, or to hold the instrument in the hand, invert the box, and place it over the meter. Do not remove the base or cover from any instrument outside of the laboratory, as, in doing so, particles of dirt and lint are almost certain to get into the instrument, causing friction which several hours of close examination may be required to detect.

When connected to the circuit, arrange the leads so that the instrument cannot be pulled from the table.

Never place the instrument on a bench or other support which is subject to vibration from adjacent machinery.

Be sure that the current and potential are within the range of the

instrument about to be used. A voltmeter used in measuring the voltage across a highly inductive circuit may be damaged by the inductive "kick," due to the collapsing of the magnetic lines of force; such condition would arise in the case of a continuous current voltmeter used in connection with an ammeter for the measurement of the resistance of a transformer, provided the circuit is broken before the voltmeter is disconnected.

When a wattmeter potential circuit or a voltmeter is connected across part of a circuit in which the line voltage is higher than the maximum range of the instrument, it is important that the part of the circuit between the instrument terminals should not be broken while the instrument is connected. To do so would, in most cases, place the total line voltage across the meter. Disconnecting a series instrument while the potential instruments are connected to the line side of it, is a common cause of such accidents.

Never leave a low-reading voltmeter connected to the circuit. It is best to keep voltmeters disconnected at all times when readings are not being taken. Series instruments can be protected to some extent by having switches arranged to short circuit them, the switch being opened only when a reading is to be taken. Fuses or circuit breakers can be used to prevent the winding from being actually burned out, but they cannot prevent the mechanical shock to the movable element, subjected to such overload. With series instruments having considerable resistance, a short circuiting switch may not be applicable, especially if the voltage of the circuit is low. If the current were adjusted with the instrument in circuit, the short circuiting of the instrument might cause an undesirable rise of current.

When using wattmeters on circuits of 500 volts and upward, always protect the movable element by connecting the correct potential post (depending on the type of instrument employed) to one of the current posts by means of a fuse wire. Either current post may be used; but if the one connected direct to the load is chosen, the indication of the wattmeter will include the watts lost in its own potential circuit.

When making tests upon high-voltage circuits, one of the greatest sources of error is that produced by "static," which causes the instrument to appear sticky, or causes the indicator to deflect above or below zero before the circuit has been completed. This source of error can usually be eliminated by connecting one binding post to the metal cover by means of a fine wire, and, in addition, covering the bench beneath the instrument for about 18 inches square with tin

foil, and connecting this to the cover. Under no circumstances should a sheet of copper, iron or brass be used for this purpose, or any metal having an appreciable thickness, as eddy currents may be set up in the mass of metal, and these, reacting upon the fields produced by the currents in the windings, may cause incorrect readings. This remedy can be applied, with safety to the instruments, to ammeters only, as, in cases where voltmeters or wattmeters are used in connection with multipliers, should the wrong binding post be connected to the cover, and the static effect, in consequence, not be removed, the instrument is very liable to be burned out by the indicator swinging against the cover.

A great many types of instruments are susceptible to stray fields arising from some particular condition of the test circuit or its surroundings. A knowledge of the principle upon which an instrument operates, the location of its windings, and its magnets, if any, should enable the user to judge whether or not the location is suitable, and guide him as to the proper precautions to take to obtain accurate results.

Alternating and continuous current ammeters and wattmeters made for heavy currents are likely to have only a turn or two in the coils carrying the main currents. It is then a matter of importance in connecting them, to bring the leads to them in such a way that they do not form a loop which can set up a magnetic field, aiding or opposing that of the instrument winding. The best way of doing this is to keep them very close, preferably twisted together for some distance away from the instrument. With alternating currents there is less chance of disturbing influences apart from the apparatus in the circuit than with continuous currents, because only alternating fields at the frequency of the circuit, and having a fairly constant phase-relation with it, can affect the instruments. This practically limits the stray field influence to that of the instruments and other apparatus in the circuit upon each other. It will be remembered, however, that instruments designed for both alternating and continuous current are more susceptible to influence from conductors than are continuous current instruments.

In general, it may be said that there are more opportunities for error in measuring heavy currents than in measuring small ones. In continuous current work there may be disturbing influences entirely apart from the apparatus in use on the test; such, for instance, as the field of a motor or generator or a near-by bus-bar carrying heavy currents. Instruments containing permanent magnets will, if placed too close together, influence each other. The natural tendency

is to place them in almost the worst possible position; that is, side by side. A space of from two to three feet may be taken as a safe distance to allow between continuous current instruments of the ordinary portable type. When space is very limited, two instruments can often be brought close together without causing trouble, by placing one of them with its scale inverted with respect to the other, so that the neutral parts of the magnets are nearest to each other and the pole pieces as far apart as possible. For the most accurate results even the earth's magnetic field must be taken into account, the maximum possible variation in reading from this cause being usually a little more than one-tenth of one per cent in the case of permanent magnet instruments.

With the exception of astatically wound instruments, electrodynamometer instruments designed for use on both alternating and continuous currents, when used on continuous current must be read with the current first in one direction and then in the other; the average of the direct and reverse readings gives the true reading if the scale is uniform. If all external magnetic fields acting upon the instrument are independent of the current in the circuit, the reversal can be made at any convenient point, but if there is a probable influence from the conductors or apparatus in circuit, it is best to make the reversal at the terminals of the instrument in order to correct for all stray fields at once.

The foregoing remarks do not apply to induction instruments as the principle upon which they are made is such that a stray field could scarcely enter in a way that would affect them. Neither do they apply to electrostatic and hot-wire instruments. There are so many things which tend to prevent accurate work with the latter two classes of instruments that they are little used in ordinary testing. Their most valuable property is that the voltmeters are independent of the frequency. Electrostatic voltmeters have the additional feature which is valuable in certain kinds of work, that the energy required to operate them need not be considered.

Instrument transformers are divided into **two general classes,** known as **current transformers** and **voltage transformers.**

These devices, when properly designed, may be used to advantage in extending the range of voltmeters, ammeters and wattmeters, or watthour meters, or where it is desirable that measuring instruments be insulated from the testing circuit. Considered electrically, without reference to features of design, current and voltage transformers differ simply in the methods of use.

There are three essential parts to an instrument transformer: a primary

or high-tension, electrical circuit; a secondary, or low-tension, electrical circuit; and a magnetic circuit, with which these are interlinked. The high-tension winding is connected to the supply circuit, and the low-tension winding to the measuring apparatus.

Instrument transformers, when properly designed, are suitable for measurements of high accuracy, for, when their constants have been accurately determined, the precision of the results obtained depends chiefly upon the instruments used with them, as the transformers are more permanent and less liable to injury than measuring instruments of delicate construction.

The intention is not to discuss the design of voltage and current transformers, or the methods of obtaining their constants, but rather to indicate the application of these instruments, the nature of the correction necessary, and the best methods of applying them to a given set of measurements.

Both current and voltage transformers are subject to errors of more or less magnitude, due to variations of primary current or voltage, to frequency, or to the amount and character of the secondary load.

The determination of transformer losses is a familiar test, and the measurement of ratios is not difficult, and may be accomplished without the employment of complicated apparatus, but the determination of phase relations involves the use of apparatus not usually found in the central station laboratory, and where it is desired to use instrument transformers for power measurements, it is better to have their constants certified to by a responsible testing laboratory than to attempt to determine them by means of inadequate apparatus, or methods, which may not be correct.

The ratio of a voltage transformer is quite definitely determined by given conditions, and, with a definite secondary load, is little affected by variation of voltage or moderate variation of frequency and wave form. Consequently, if a voltage transformer be calibrated for the value of its ratio with different low-tension circuit impedances, it may be used as an instrument of precision.

Voltage transformers are usually wound for some convenient integral value of the ratio of high-tension applied voltage to low-tension terminal voltage.

The ratio of voltage transformers can be checked readily by comparison with a voltage transformer, the ratio of which has been determined by some reliable testing laboratory. The primary of the standard transformer and the transformer to be tested should be excited at the voltage at which the latter is to be used, and the secondary voltages read on two voltmeters, or if a steady voltage is obtainable, on one voltmeter

thrown quickly from one transformer to the other by means of a double throw switch. The latter method is preferable, as with transformers of equal ratio, the accuracy of the voltmeter does not enter. Where two voltmeters are used, their accuracy should be checked at the points used. The transformer being tested should carry the same secondary load as it will in service.

In any given system, the voltage transformers are usually all of the same potential, or a very small number of standard potentials, so that the apparatus required for this test is not great.

The question of change of ratio at low voltages does not arise in practice, as voltage transformers are usually operated close to some standard value of line voltage. In well made voltage transformers the phase angle is negligible, for practical purposes, as long as the current taken from the low-tension winding is not too great. When used with wattmeters, or watt-hour meters, on low power-factors, however, this angle should be determined. Care should be taken not to exceed the rated capacity of the low-tension circuit; if the instruments used are inductive, the volt-amperes they require may be counted as so many watts in estimating the load on the transformer low-tension winding.

The term "**secondary load**" is applied to the devices connected to the secondary of an instrument transformer, which are supplied with energy to operate through the transformer.

This load and its power-factor should be clearly distinguished from the load and power-factor of the high-tension circuits.

In a voltage transformer an increase in the low-tension circuit impedance tends to raise the low-tension voltage, and to decrease the phase displacement between the high-tension and low-tension voltages.

The effect of an increase in the secondary impedance of a current transformer is to lower the secondary current, and to increase or decrease the phase displacement between primary and secondary currents, depending upon the power factor of the secondary load; these effects are greater for small currents.

Alternating current ammeters do not, as a rule, lend themselves readily to operation from shunts; further, the same necessity frequently exists in this case, as for the voltmeter, of insulating the instrument from the line voltage.

The current transformer accomplishes both functions, and when well designed, constructed of proper materials, and not required to operate too many instruments, is a very satisfactory piece of apparatus.

As the current transformer is used for the purpose of producing a

current having a known ratio to the current to be measured, a knowledge of the conditions which affect ratio should be the first requisite in putting them into service. Ratios vary a great deal more in some transformers than in others, but it is safe to say that no transformer gives a constant ratio at all loads from its full rated capacity to an extremely small fraction thereof. The general statements here given apply to current transformers as a class. The magnitude of the errors in any given case depend on details of design and materials.

The ratio near full load is less subject to error than that at lower loads. The chief cause of error in ratio is the employment of an impedance in the secondary circuit higher than that for which the transformer was designed.

A number of methods of measuring **current transformer ratios** have been devised, but many of them are not suitable for the ordinary central station laboratory equipment.

Current transformer ratios can be measured readily by connecting a watt-hour meter, or rotating standard, of known accuracy in the secondary, and a standard indicating wattmeter in the primary, the potential circuits of the two meters being connected at the same point to a potential in phase with the primary current.

Readings are then taken in the same way as for a primary calibration of the watt-hour meter, and the percentage accuracy obtained for the combination of transformer and watt-hour meter divided by the known percentage accuracy of the watt-hour meter alone will give the accuracy of transformer in per cent of registration. The true ratio of the transformer will be obtained by dividing the nominal ratio by the percentage accuracy. This method is simple in application and is as accurate as the indicating wattmeter used, and uses the normal load for the transformer where transformers are used with watt-hour meters only. Where the primary current is too large to use on the indicating meter, a five ampere standard indicating wattmeter can be used on the secondary of a current transformer whose ratio has been determined for use under that condition by a reliable testing laboratory.

If preferred, the secondary can be measured by an indicating wattmeter and the ratio will be primary watts divided by secondary watts.

Increasing the impedance of the secondary circuit causes a decrease in the secondary current resulting from a given current in the primary. Since the proportional decrease is greater at the low loads than at the high ones, it follows that if the secondary impedance is increased at the low loads only, by exchanging an instrument used at the high loads for one which will give a more legible reading at the low ones, the discrepancy in ratio is likely to be large. The low reading instrument

invariably has a higher impedance than the one of larger capacity and this additional impedance is introduced into the circuit while making the very measurements which will be most influenced by it. This point cannot be too strongly emphasized, because it is so easy to fall into the error of measuring the currents at different loads with different ammeters in the secondary circuit. Few alternating current instruments can be read with accuracy at loads below thirty per cent of their full-scale readings. It is not unnatural, then, to change ammeters two or three times in taking readings on a wide range of currents.

Watt-hour meters which have a range of accurate calibration from two to one hundred and fifty per cent of their rated loads are used extensively in connection with current transformers. It is therefore necessary that the performance of the transformer throughout the same range be known. To measure the ratio with ammeters, keeping the readings always above one-fourth scale, would necessitate at least three changes even if it is assumed that ammeters of the exact capacities required are available. Since alternating current ammeters of the same type have impedances approximately in inverse proportion to the squares of their capacities, it is evident that the secondary impedance could easily be sixteen times as great at the low readings as at the high ones.

Ratio curves so determined are useful if used in connection with the instruments and transformers for which they were made, or their counterparts. If a smooth curve is made and applied indiscriminately to a certain transformer it is worse than useless, for it may lead to the placing of confidence in results that are in greater error than would have resulted if there had been no attempt to correct for error in ratio.

As the impedance of the series coil of a wattmeter is lower than that of an ammeter, of the same capacity, the ratio of transformation is correct over a wider range. The nearer the approach to a short circuited secondary, the wider is the range of loads at which the ratio is constant.

The ratio of an instrument transformer is correct in one direction only. For example: a current transformer which is designed to give five amperes secondary current with twenty amperes primary current, or a ratio of four to one, will not produce satisfactory results when connected to the same ammeter in the reverse order for measuring currents of 1.25 ampere or less, that is in the ratio of one to four. It is true that if the heavy-current terminals are short circuited, an alternating current passed through the low current coil will induce a comparatively heavy current in the other side, but the ratio is not accurate enough for the purpose of measurement.

The same thing is true of a voltage transformer. One which is designed to give a 10 to 1 ratio from high-tension side to low-tension sid

voltage, will not give an exact 1 to 10 ratio when excited from the low-tension side. These conditions are the result of providing one of the windings with compensating turns to correct for the losses in the transformer.

For measurements of voltage or of current it is necessary to know only the ratio of transformation involved, but for measurements of power with a wattmeter, or watt-hour meter, **the phase relations** are also involved, and accuracy cannot be assured unless these are known, and proper correction made. In the operation of these latter instruments with current transformers, **two sources of error** arise; **first,** as in the case when ammeters are used, the ratio of transformation varies with the primary current, the rate of change of the ratio (for a given transformer) being greater the smaller this current; **second,** the secondary current is not exactly in opposition to the primary current, and this deviation from opposition (usually referred to as the "phase angle") will usually increase as the load decreases. The light load performance of the transformer will of course depend in the first place upon its design and the quality of the materials used in its construction, but for a given transformer the general performance will be better the smaller the load of instruments it is required to operate; that is, the lower the resistance and the reactance of the secondary circuit. As both ratio and phase angle errors affect the reading of a wattmeter, or watt-hour meter, care should be taken that the current transformer used with these instruments is of proper design and capacity and that it is not overloaded with instruments.

It is unsafe to open the secondary circuit of a current transformer when there is any current in the primary. When the secondary circuit is closed, the current in this circuit forms a magnetomotive force, which is in opposition to the magnetomotive force of the primary current, and the core flux is thereby limited to the value necessary to generate in the secondary coil an e.m.f. sufficient to produce therein a current only slightly less than the primary current in magnetizing effect. When the secondary is open, there is no opposing magnetomotive force for limiting the core flux, which therefore reaches a value determined solely by the primary magnetomotive force divided by the reluctance of the transformer core. The design is such that the reluctance is very low and the flux reaches a relatively high value before the core becomes saturated. Thus even a small value of primary current produces an excessive value of core flux and a correspondingly large e.m.f. in each secondary turn. The secondary voltage under these conditions reaches a value which may both damage the insulation and prove **dangerous to life.**

The ratio and phase angle will also be changed, as the iron is not left in a magnetically neutral condition, so that both the magnetizing current and the core loss are increased, thus changing the constants of the transformer.

When current transformers are used for testing with indicating instruments in the laboratory, there are other considerations apart from those of personal danger from the high secondary e.m.f. at open circuit, and of possible damage to the transformer itself by overworking its iron. There is a probability of overloading other apparatus in the circuit, if the current or e.m.f. of the line are adjusted before closing the secondary. The impedance of the primary is dependent upon that of the secondary. If the latter is low, the e.m.f. across the former at full load will be very small. With open secondary, the primary impedance would in some instances be such a large portion of the total impedance in the circuit that an excessive current would flow at the instant of closing the secondary, and thereby cutting out the primary impedance.

Absolutely no harm can come from short circuiting the secondary terminals of the current transformer, and this method is used when it is necessary to insert, or disconnect, instruments in the secondary circuit.

If continuous current is passed through a current transformer, the magnetizing current and core loss are increased, and the constants are changed in the same manner as when the secondary is open circuited with load on the primary.

A transformer which has been subjected to continuous current, or has been open circuited, should be carefully demagnetized before its indications are relied upon for accurate measurements.

Demagnetization may be carried out by passing full load alternating current through the primary, while the secondary is open, and gradually reducing the current to zero. The demagnetization may also be accomplished by inserting a suitable value of resistance (about 10 ohms) in the secondary circuit with full rated alternating current through the primary winding, and gradually reducing either the current or the resistance to zero.

In the selection of suitable instrument transformers for use with secondary standards care should be taken to insure that the volt-ampere rating of the transformer is sufficient to permit the use of the desired instruments in the secondary. The ratio of transformation should be so compensated that a large correction factor is unnecessary; and the angular displacement between primary and secondary current should not deviate from 180 degrees by an excessive value. Voltage transformers may be obtained in which the phase angle does not deviate from the theoret-

ical position more than an angle of ten minutes, while current transformers are available in which the displacement does not exceed an angle of forty-five minutes at ten per cent load. The performance of the transformers at the frequency at which they are intended to be used should be investigated. The insulation between the primary and secondary windings should be at least double the amount actually required for the voltage of the circuit upon which the instrument is to be used.

It is customary to mark on watt-hour meters designated for use with instrument transformers, the constants referring to energy in the primary circuit. In testing watt-hour meters of this class with standards in the secondary circuit, the constants as marked should be divided by the product of the nominal ratios of the transformers to obtain the watt-hour meter constants. The errors of the instrument transformers should be taken into account by the use of correction curves in the manner specified herein.

Watt-hour meters installed with voltage and current transformers must be correctly calibrated with respect to the energy in the primary circuit.

A correct calibration is obtained directly by connecting the standards in the primary circuits of the transformers. In such tests, the impedance in the secondary circuit of the transformer should be the same as in service. This procedure should be followed where feasible.

In the case of high voltage, or heavy current, conditions, and in any cases where primary tests are difficult or impossible, recourse may be had to secondary tests; provided, however, that the transformer errors are determined, and are taken account of in the calibration of the watt-hour meters under test. The percentage of accuracy of the watt-hour meter should be adjusted to correspond to a predetermined correction curve, which gives at each load the amount by which the percentage of accuracy with respect to secondary energy must differ from 100 per cent, in order to correct for the transformer errors. This value of watt-hour meter accuracy is hereinafter for brevity referred to as the secondary accuracy.

The **permanency of commercial transformers** is such that their ratios may be relied upon to remain unchanged for a period of five years (but not longer without calibration), provided that the transformers have not been subjected to overloads, primary short circuits, or open circuiting of the secondary of the current transformer under load.

The phase displacement in the voltage and current transformers will appreciably affect the accuracy of the watt-hour meter only at low power-factors.

The effect will be equivalent to a certain error in the lag adjustment, and may be compensated by relagging the watt-hour meter in the laboratory prior to installation.

With standards in the primary circuit, the watt-hour meter is lagged in the same manner as a meter without transformers; that is, the meter is adjusted correct at unity power-factor by means of the full load and light load adjustments, after which the meter is tested at one load at a low power-factor and its accuracy adjusted to 100 per cent by altering the lag adjustment.

In lagging the watt-hour meter by means of standards in the secondary circuit, it is necessary to have two correction curves, one corresponding to unity power-factor, and the other to a lower power-factor (70 per cent or 50 per cent is suitable). The procedure is the same as in lagging from the primary, except that the percentage of accuracy is adjusted in each case to conform to the corresponding calibration curve.

Owing to the fact that the phase displacement of a current transformer varies with the load, it is impossible to obtain a lag adjustment which is absolutely correct for all loads. Errors from this source may be minimized by the use of transformers having a small phase angle, and by making the lag adjustment at a load representing as nearly as possible the normal load of the circuit on which the watt-hour meter is to be used.

In **primary tests,** where the voltage and current exceed the range of ordinary wattmeters and rotating standards, portable current and voltage transformers may be used in connection with low range standards. The correction curve of the combination is obtained by testing the standard in conjunction with the transformers, or by applying the corrections given at the close of this chapter, to the correction curve of the standard, as determined without the transformers.

In **testing watt-hour meters used with current transformers** special **methods of loading** are often necessary. The methods and diagrams to be used are similar to those discussed in Chapter VII and Chapter VIII, and are briefly referred to here.

Where the primary voltage is low, permitting loading the watt-hour meter and transformer together from the primary, the current will ordinarily be so large as to preclude the use of load boxes of the ordinary capacity. Stepdown transformers may be used to furnish the large currents.

In testing on low voltage circuits with standards in the secondary, the loads may be obtained very conveniently by short circuiting the current transformer, then disconnecting the watt-hour meter from the current

transformer and loading it independently, obtaining energy from the primary circuit.

Where the primary voltage is high, the current for tests may be obtained from the secondary of a stepdown transformer supplied by the same system.

If it is possible to disconnect the current transformer from the high voltage circuit, a primary test may be made by including the current transformer together with the standard in the secondary circuit of the stepdown transformer, the voltage connections of the watt-hour meter remaining undisturbed.

Where no low voltage circuit is available, it is necessary to make the secondary test, inserting the standards in the secondary.

Light load tests may be made by loading the watt-hour meter from the low-tension side of the voltage transformer, providing the capacity of the transformer will permit.

Where **secondary tests** are made **at a low power-factor,** the watt-hour meter should be adjusted to the value of secondary accuracy corresponding to the actual power-factor. If the watt-hour meter has been previously relagged with respect to the primary this renders the meter correct at all power-factors.

The calibration curve may be determined by a comparison of primary and secondary tests. If the meter is adjusted correctly with respect to primary energy, the secondary accuracy is observed directly. When the percentage of accuracy in terms of primary energy differs from 100 per cent, the true secondary accuracy is computed by dividing the observed secondary accuracy by the actual primary accuracy.

The correction curve is computed from the ratio and phase displacements of the transformers, determined by independent precision measurements as follows:

At unity power-factor,

$$\text{Secondary accuracy} = \frac{\text{true ratio of current transformer}}{\text{nominal ratio of current transformer}} \times \frac{\text{true ratio of voltage transformer}}{\text{nominal ratio of voltage transformer.}}$$

At the power-factors other than unity, the secondary accuracy is determined by adding to or subtracting from, the value given by the above formula, the quantity

$$\tan\phi \tan\delta \times 100 \text{ where}$$

ϕ = phase difference between secondary current and secondary voltage, that is

$$\cos \phi = \text{secondary power-factor,}$$

which may be determined by voltmeter, ammeter and wattmeter readings in the secondary.

δ = resultant phase displacement introduced by the two transformers.

The sign of the correction is to be determined from the following table, in which

β = phase angle of secondary current with respect to primary current.
γ = phase angle of secondary voltage with respect to primary voltage.

Table for Determining Signs of Corrections.

(a) β numerically larger than γ

ϕ	β	γ	δ	Correction
Lagging	Lagging	Lagging	$\beta - \gamma$	Additive
Lagging	Lagging	Leading	$\beta + \gamma$	Additive
Lagging	Leading	Leading	$\beta - \gamma$	Subtractive
Lagging	Leading	Lagging	$\beta + \gamma$	Subtractive
Leading	Lagging	Lagging	$\beta - \gamma$	Subtractive
Leading	Lagging	Leading	$\beta + \gamma$	Subtractive
Leading	Leading	Leading	$\beta - \gamma$	Additive
Leading	Leading	Lagging	$\beta + \gamma$	Additive

(b) γ numerically larger than β

ϕ	β	γ	δ	Correction
Lagging	Lagging	Lagging	$\gamma - \beta$	Subtractive
Lagging	Lagging	Leading	$\gamma + \beta$	Additive
Lagging	Leading	Leading	$\gamma - \beta$	Additive
Lagging	Leading	Lagging	$\gamma + \beta$	Subtractive
Leading	Lagging	Lagging	$\gamma - \beta$	Additive
Leading	Lagging	Leading	$\gamma + \beta$	Subtractive
Leading	Leading	Leading	$\gamma - \beta$	Subtractive
Leading	Leading	Lagging	$\gamma + \beta$	Additive

Usually ϕ is lagging, β and γ leading and β larger than γ in practice, corresponding to the third case under (a) so that the correction is usually subtractive.

Table of Values of Tan ϕ Tan δ × 100

Power-Factor in Secondary

	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95
	Percentages										
20′	1.2	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.4	0.3	0.2
40′	2.3	2.0	1.8	1.5	1.4	1.2	1.0	0.9	0.7	0.6	0.4
1°00′	3.5	3.0	2.7	2.3	2.0	1.8	1.5	1.3	1.1	0.8	0.6
1°20′	4.6	4.0	3.5	3.1	2.7	2.4	2.1	1.7	1.4	1.1	0.8
1°40′	5.8	5.0	4.4	3.9	3.4	3.0	2.6	2.2	1.8	1.4	1.0
2°00′	6.9	6.0	5.3	4.7	4.1	3.6	3.1	2.6	2.2	1.7	1.1
2°20′	8.1	7.1	6.2	5.4	4.7	4.2	3.6	3.1	2.5	2.0	1.3
2°40′	9.2	8.1	7.1	6.2	5.4	4.7	4.1	3.5	2.9	2.3	1.5
3°00′	10.4	9.1	8.0	7.0	6.1	5.3	4.6	3.9	3.2	2.5	1.7
3°20′	11.6	10.1	8.8	7.8	6.8	5.9	5.1	4.4	3.6	2.8	1.9
3°40′	12.7	11.1	9.7	8.5	7.5	6.5	5.7	4.8	4.0	3.1	2.1
4°00′	13.9	12.1	10.6	9.3	8.2	7.1	6.2	5.2	4.3	3.4	2.3
4°20′	15.0	13.1	11.5	10.1	8.9	7.7	6.7	5.7	4.7	3.7	2.5
4°40′	16.2	14.1	12.4	10.9	9.5	8.3	7.2	6.1	5.1	4.0	2.7
5°00′	17.4	15.2	13.3	11.7	10.2	8.9	7.7	6.6	5.4	4.2	2.9

CHAPTER VI

METER SHOP

CHAPTER VI

METER SHOP

The meter shop is the general term applied to the quarters in which the mechanical work connected with the operation and maintenance of service watt-hour meters is carried on, and also the office work when this is not conducted separately from the other.

It may be subdivided into the following different rooms:

Office.
Laboratory.
Instrument Room.
Testing Room.
Repair Room.
Stock Room.

It is not customary, however, to segregate the work to such an extent, and in a small company all the work may be carried on in one room.

The importance of careful and economical work should be kept in mind in selecting the location of the meter shop. The quarters should be centrally located with reference to the district served, should be well lighted and ventilated, and so heated that as even a temperature as practicable can be maintained. It is important also that the building should be practically free from vibration, or else the testing tables should be supported on separate foundations. The floors should be of hard wood, or cement treated with a special preparation, so that they can be kept free from dust, which is important, because the covers of the watt-hour meters and indicating instruments are often removed during testing or repairs.

The office equipment should consist of suitable desks, cabinets for card records and filing cases, so that all records can be kept systematically, and referred to without loss of time.

The laboratory equipment should consist of instrument tables, preferably with slate tops; one for permanently mounting the potentiometer, Wheatsone bridge, and other permanently connected instruments, and another for experimental work and instrument check-

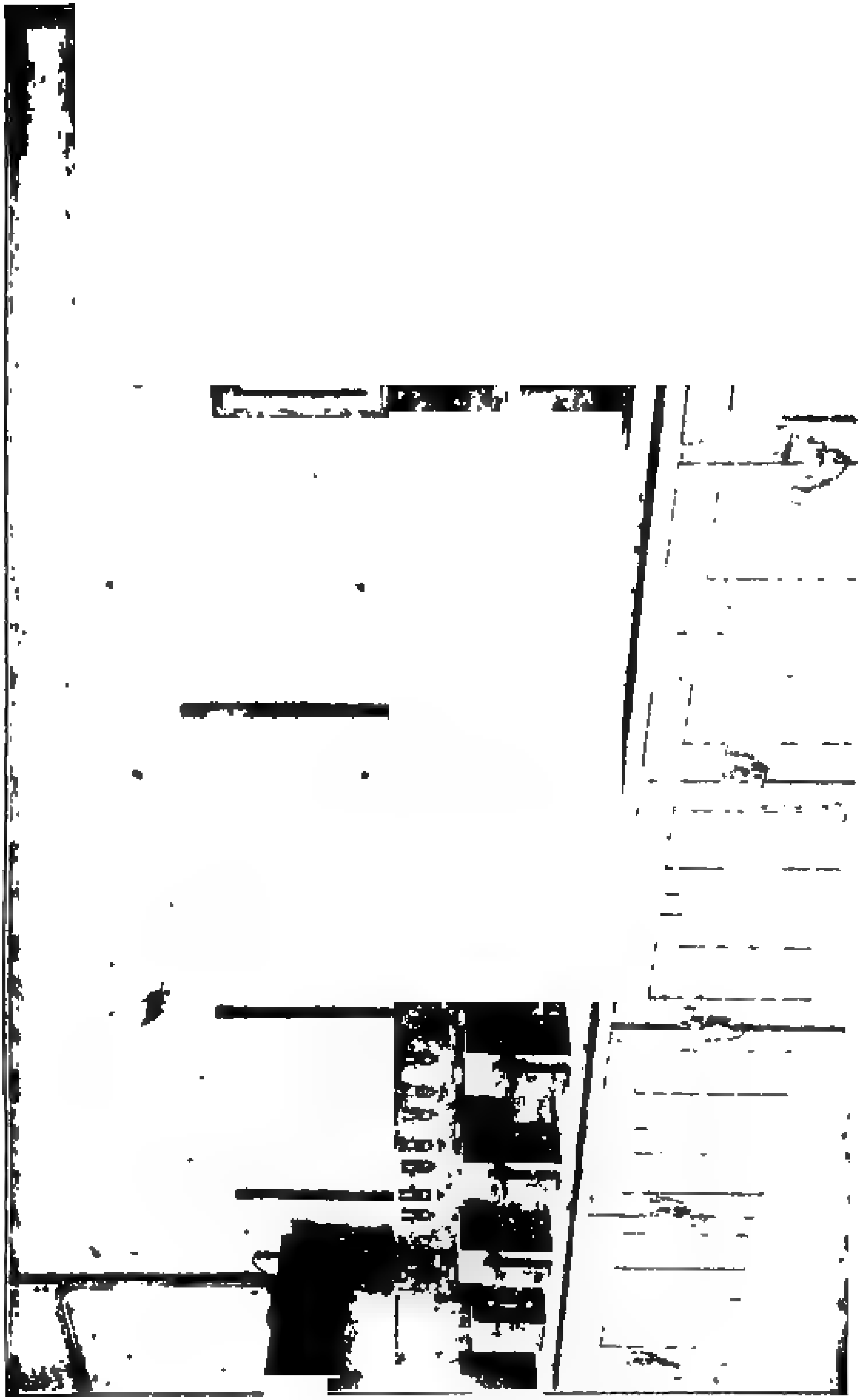
ing, which should have a suitable service outlet board over it, from which can be obtained any kind of current necessary, such as that from storage batteries, a motor generator set, or the system, as desired. There should be a work bench with a small vise; also, cabinets for storing standard shunts, instruments, and other equipment, as necessary. The equipment of electrical standards and instruments has already been described in the preceding chapter.

The instrument room may be a part of the laboratory, but it is sometimes desirable to have a separate room where the working standards, or instruments used in watt-hour meter testing on the consumer's premises can be calibrated and stored (Fig. 218). The equipment should consist of suitable secondary standards, mounted permanently on tables, preferably with slate tops. These secondary standards should be calibrated in position and connected to a series of outlets over a table, or rack, on which the working standards can be placed and readily connected for the regular check. Separate equipment will be necessary for checking the continuous and alternating current instruments. A loud sounding relay connected to the primary standard clock is desirable for checking the stop watches used in service testing. There should be provided compartments for storing the instruments and auxiliary equipment used as working standards for watt-hour meter testing, when not in use or when brought in at night. A work-bench may also be provided, so that repairs to instruments and equipment can be made when necessary. It is convenient also to have a cabinet for keeping such watt-hour meter repair parts as are used by meter testers, so that they can obtain these at the time they obtain their instruments.

The testing room must be equipped for the rapid and accurate calibration of all kinds of watt-hour meters in use by the company. For that purpose suitable **watt-hour meter testing panels** should be provided.

The larger companies, where it is necessary to test a large number of meters per day, are justified in the utilization of as elaborate and expensive an equipment as the conditions demand. It is, of course, obvious that small companies should not undergo the expense of installing an elaborate system. The small companies should, however, make proper arrangements to test one or more watt-hour meters at a time, and some of the accompanying figures and diagrams indicate equipments that could be used for this purpose.

These panels should be so arranged that the meter under test will be at a convenient height, preferably about level with the meter tester's chin, and with a bench or shelf below for holding the instruments



and tools needed. Care must be taken that the wiring of the panels is so arranged that there will not be any stray magnetic fields which will appreciably affect either the working standards or the watt-hour meters under test. Adjustable clamps for holding watt-hour meters of different types or sizes should be provided when necessary. Modern types of watt-hour meters with center, top-supporting lug, will not require any means of leveling, if the meter testing panel is accurately vertical. For older types of watt-hour meters, a simple leveling device should be arranged, such as a means of swinging the bottom of the meter testing panel in or out by the use of a leveling screw, or with rotatable wedges under the bottom of the meter. If the number of different shapes of watt-hour meters used by the company is limited to a single or a few types, the leveling and other mechanical features, as well as the electrical wiring of the testing panels, can be very simply and efficiently arranged.

Switching arrangements should be provided for throwing any desired load on the watt-hour meter under test. These arrangements can also be considerably simplified if separate panels are provided for testing the different sizes of meters most in use; for example, one for 5 and 10 ampere, 110 volt watt-hour meters; another for 5 and 10 ampere, 220 volt watt-hour meters, with another to accommodate all larger sizes. There should be a service switch provided for each panel, so that all current and potential connections will be dead when the watt-hour meter is being connected for test. The use of rotating standards is particularly applicable to all meter shop testing, and when they are used, it is a convenient arrangement to set them into the top of the testing bench, so that the top of the rotating standard is on a level with that of the bench (Figs. 231 to 233).

The same **auxiliary devices**, described in Chapter IX for watt-hour meter testing on the consumer's premises, may be used in the testing room, where they can be permanently connected; in addition, other means are available which are not practicable for portable use.

For meter shop testing there may be used for loading meters:

Lamp, or resistance banks, rheostats and inductances.

Storage batteries.

Low voltage current transformers.

Low voltage motor generator sets.

Variable voltage and frequency motor generator sets. (See Chapter V.)

A lamp bank containing 100 lamps, arranged in five rows of twenty lamps each, and divided in the center, in ten rows of ten lamps each, can be easily constructed. Nine of these rows can each be controlled by a single-pole switch, and the tenth row divided into four sections

of one lamp, two lamps, three lamps and four lamps, respectively, each section being controlled by a separate single-pole switch. It will be seen that by this simple and inexpensive arrangement it is possible to obtain a load of any number of lamps from one to one hundred.

This load can be connected to either alternating or continuous current circuits; provision can be made for both 110 and 220 volts, and suitable resistances may be provided for final adjustments of

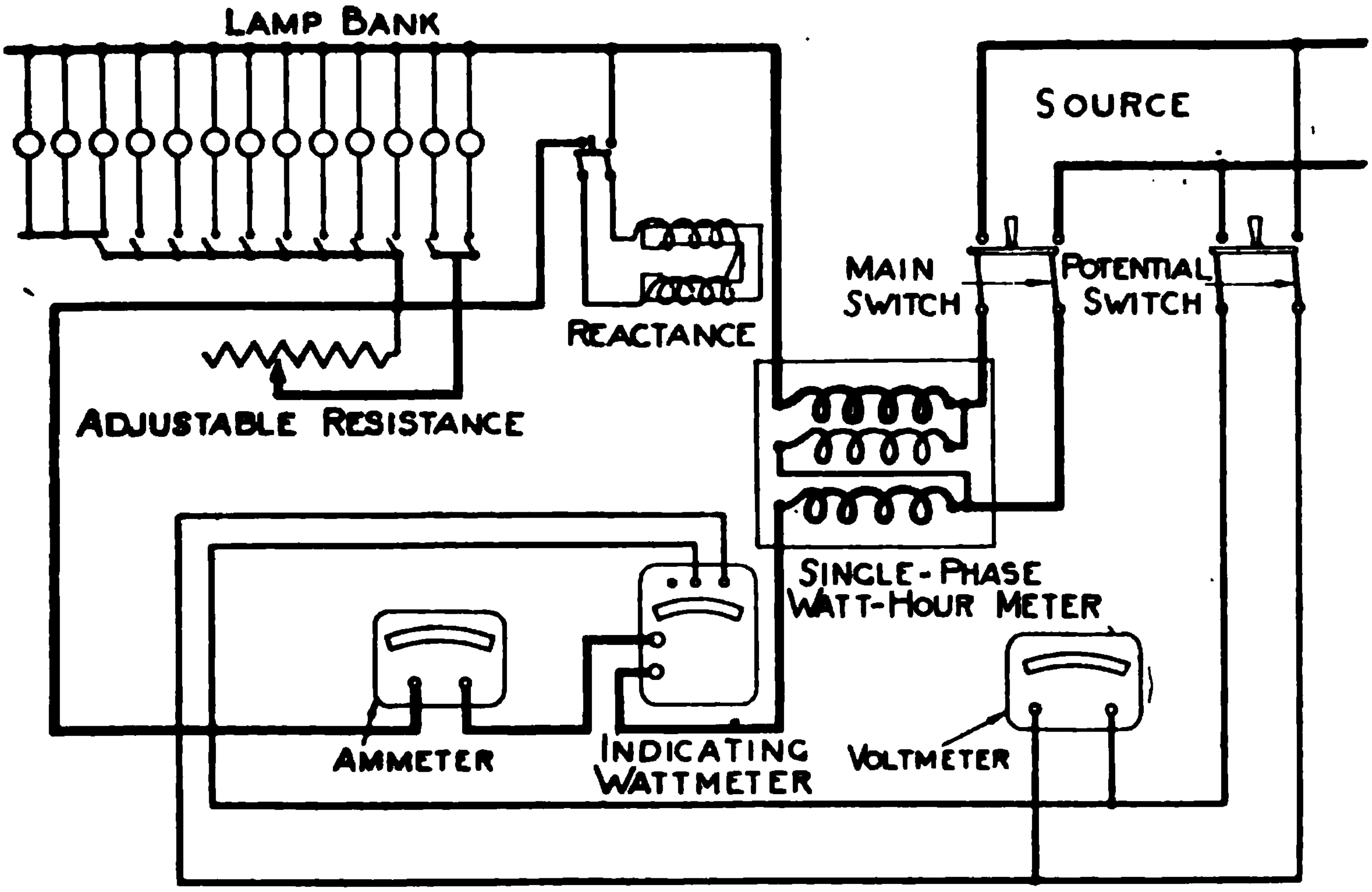


FIG. 219.—Diagram of Connections for Testing Watt-hour Meters with Lamp Bank and Reactance Coil.

both voltage and current; and any power-factor from .50 to unity can be obtained by the addition of a suitable reactance coil.

An arrangement similar to this is shown in Fig. 219.

Where **reactance coils, or transformers,** are used, care should be exercised that they are not so placed that the watt-hour meter under test, or other instruments, come within their magnetic influence.

When rotating standards are used, in meter-shop tests, it is not necessary to have absolutely steady voltage and current, such as is necessary for laboratory purposes, so that the system supply will be a satisfactory source of power for practically all purposes. For testing large continuous current watt-hour meters for which indicating instruments are usually used, unless the shunt method is used, as

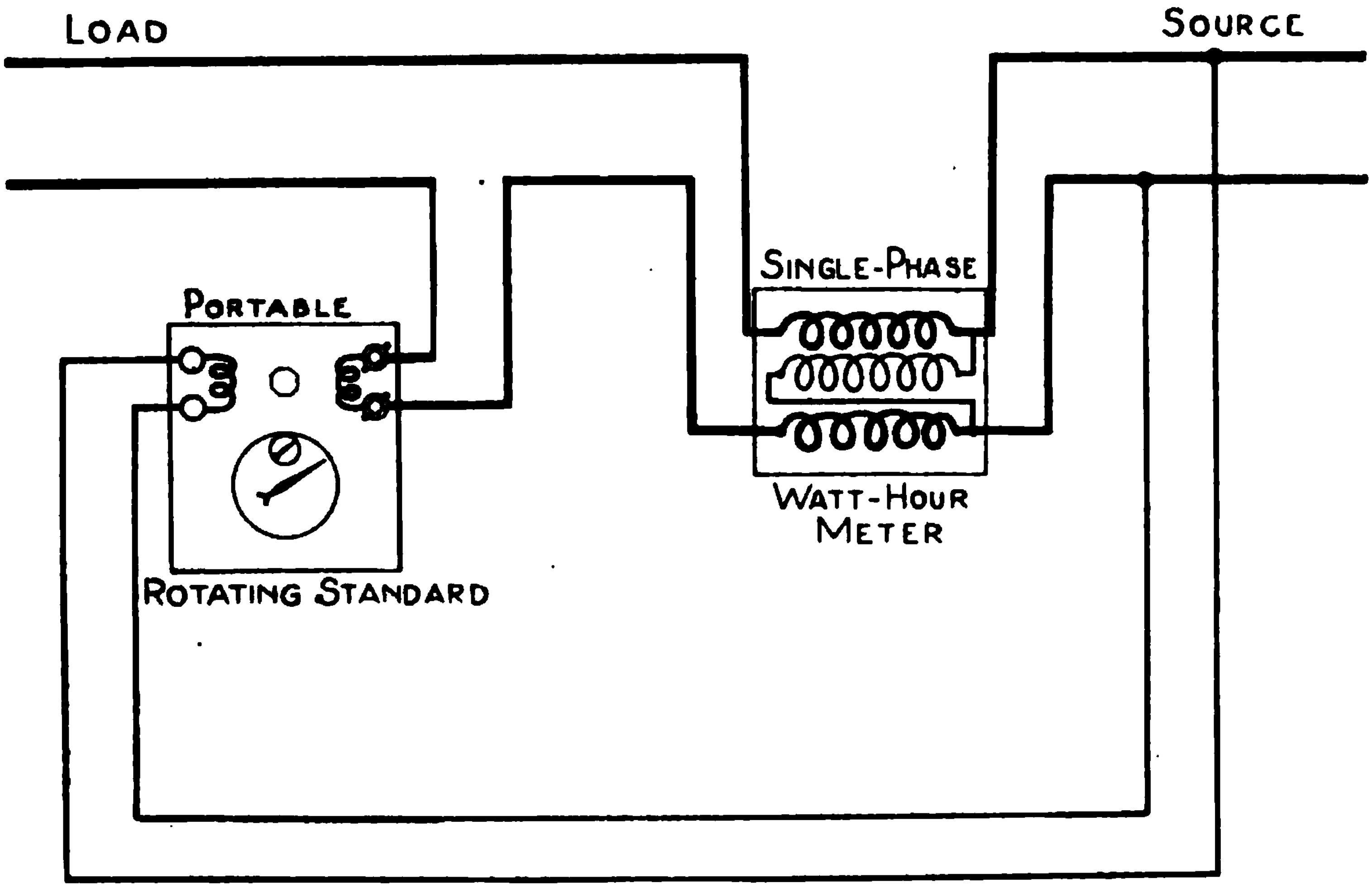


FIG. 220.—Diagram of Connections for Testing Watt-hour Meters with Rotating Standard.

described in Chapter VIII, a source of low voltage current and of potential from storage batteries is desirable.

The different **equipments for obtaining current for testing,** both

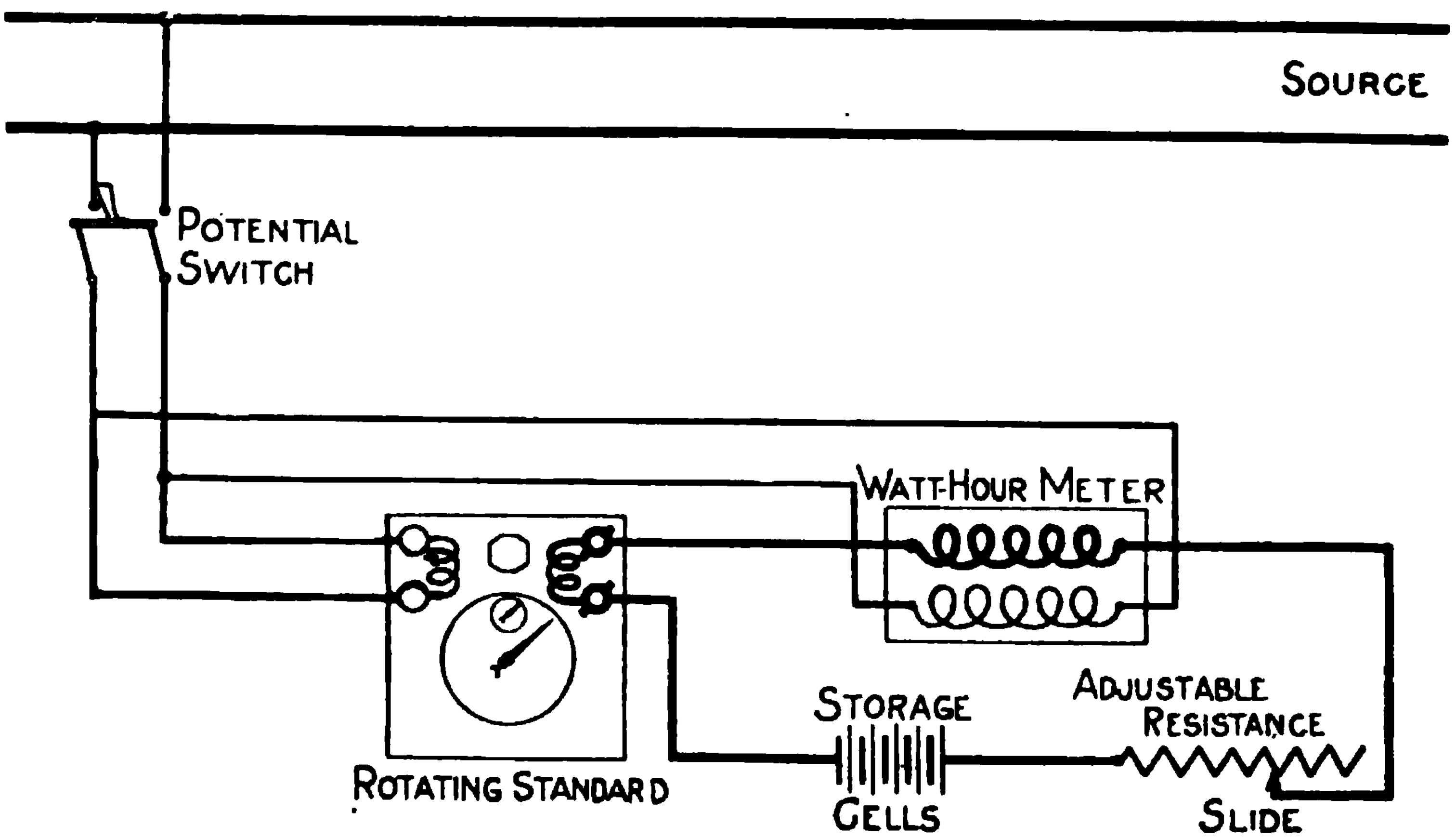


FIG. 221.—Diagram of Connections for Testing Watt-hour Meters with Storage Battery.

continuous, and inductive or non-inductive alternating current, have been described in the previous chapter.

Several **diagrams** are here given, illustrative **of different methods of current supply and testing panel connections.**

Fig. 220 shows connections for testing watt-hour meters in system service.

Fig. 221 shows the connections for testing watt-hour meters with a low voltage storage battery. Reference should be made to Chapter IX for detailed information and descriptions of them, and Chapters VII and VIII treat of methods involving their use.

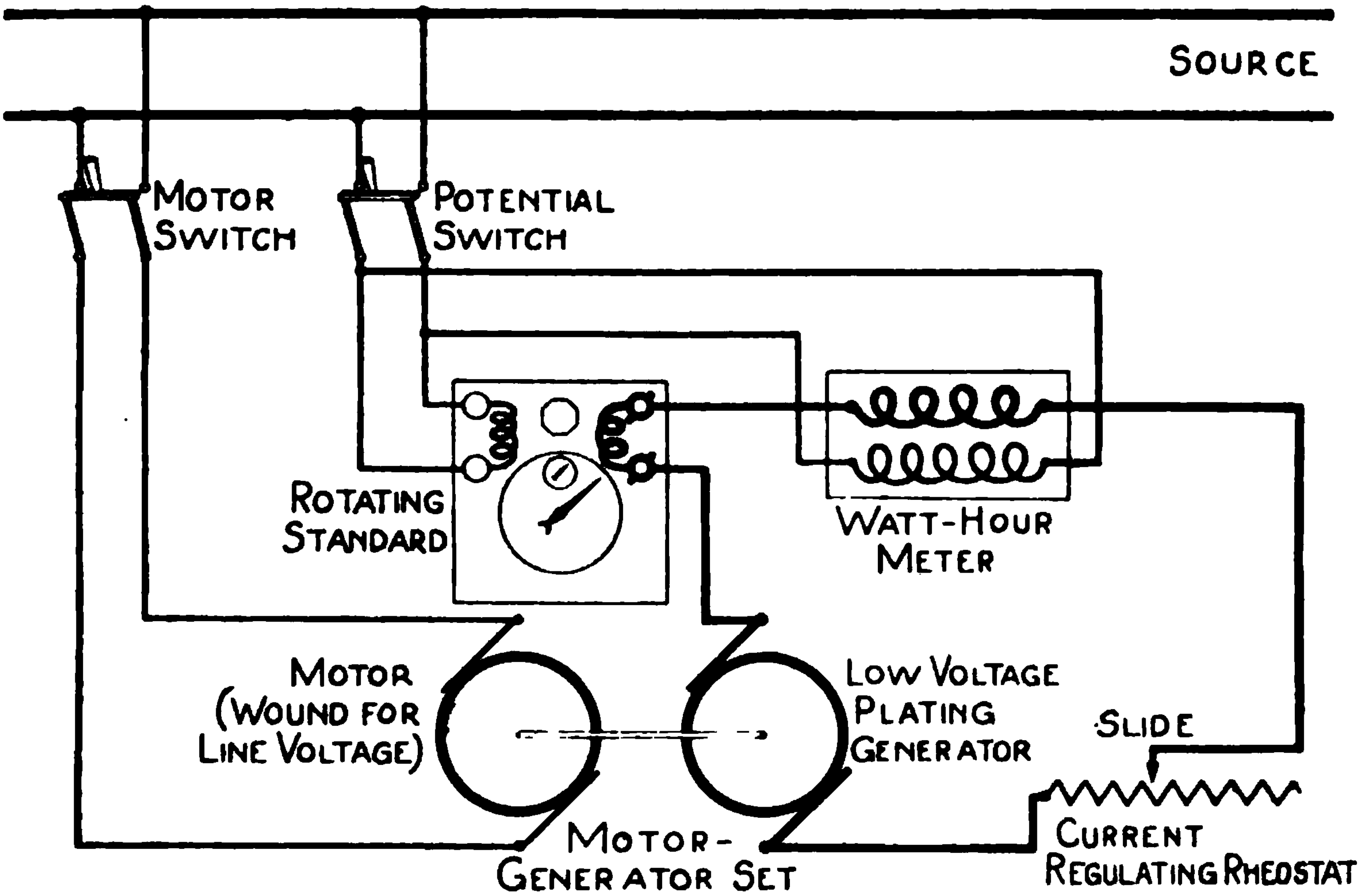


FIG. 222.—Diagram of Connections for Testing Watt-hour Meters with Motor Generator Set.

Fig. 222 shows the connections for testing watt-hour meters with a **motor generator** set, of the type generating a large current at low voltage, similar to that used for electroplating.

Fig. 223 shows connections where a low voltage transformer is used as a means of loading the watt-hour meter under test.

A convenient arrangement for loading watt-hour meters under test is shown in Fig. 224, and consists of a bank of lamps of different candle-power, ranging from 4 to 50 candle-power, these lamps being arranged in connection with single-pole single-throw switches, so that the smaller sizes may be thrown in circuit individually and

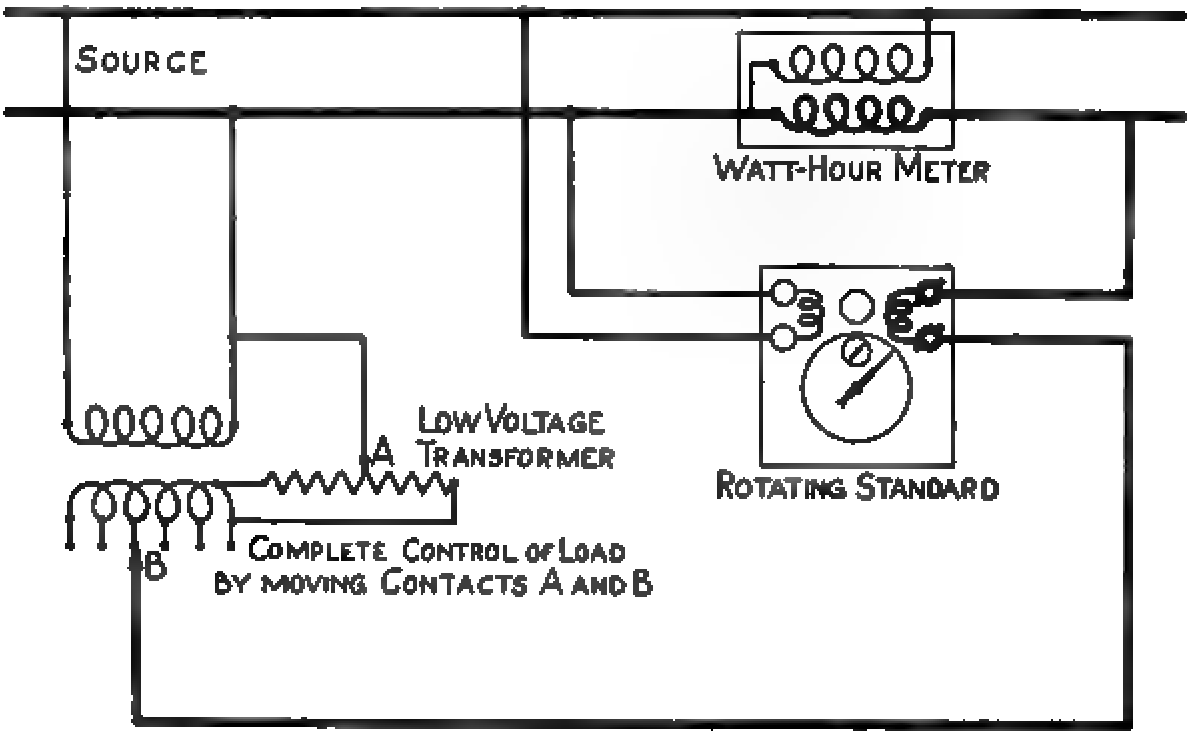


FIG. 223.—Diagram of Connections for Testing Watt-hour Meters with Low Voltage Transformer.

FIG. 224.—Diagram of Connections for Testing Watt-hour Meters with Lamp Bank.

the larger sizes in groups. This scheme may be varied to suit local conditions.

In circuit with a portion of the lamp bank is placed an adjustable resistance, or rheostat, for use in obtaining exact current values, and also to assist in maintaining a constant load. A water rheostat is very convenient for this class of work, as the load can be adjusted quickly, and with perfect uniformity. The resistance of a water rheostat can be readily changed over a wide range by changing the strength of the solution.

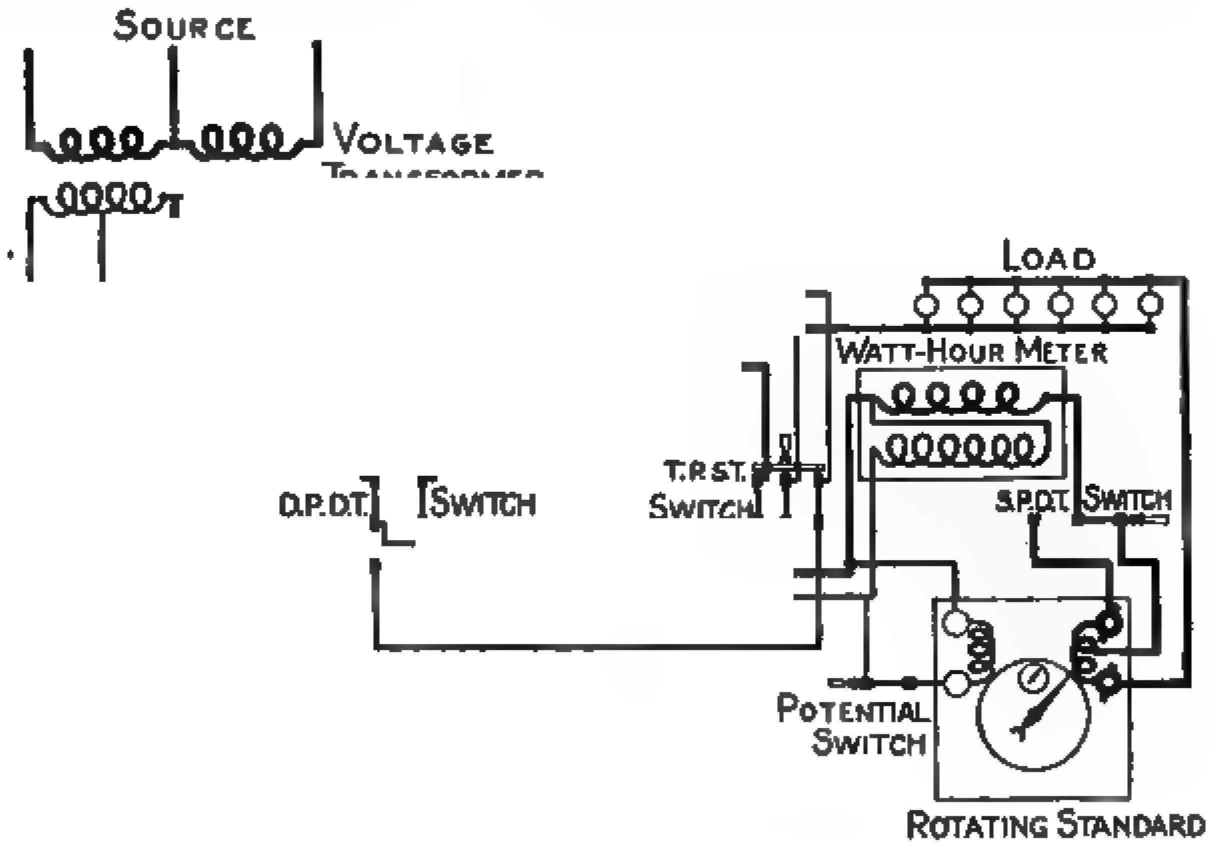


FIG. 225.—Diagram of Connections for Testing Single-phase Watt-hour Meters on Two-phase System.

A watt-hour meter can readily be checked for inductive load accuracy, if a two-phase circuit is available, by connecting the current coils of the watt-hour meter in one phase and taking the potential from the other phase as shown in Figs. 225 and 226. The meter should be given normal full load current and potential, and as the current and potential in this case are 90 degrees apart, or in quadrature, it is obvious that the meter disk should not move.

A secondary standard indicating wattmeter, or rotating standard, should be in circuit during this test, as a check upon the two-phase current be-

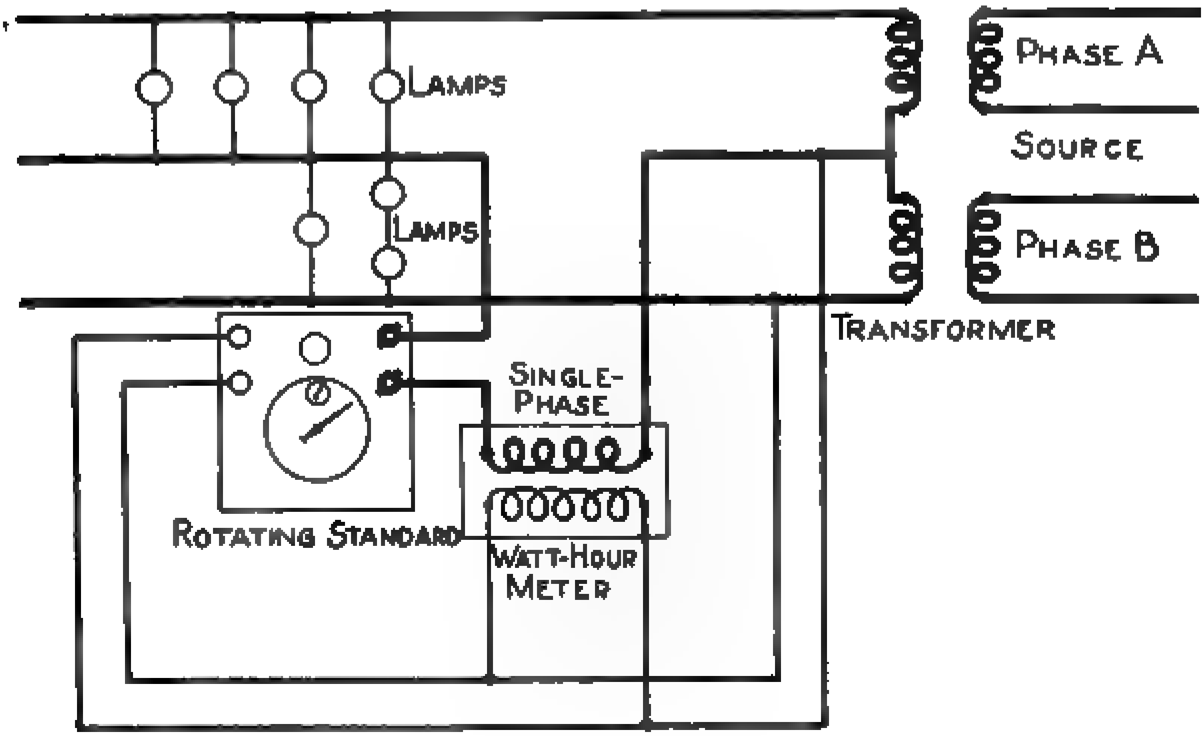


Fig. 226.—Diagram of Connections for Testing Single-phase Watt-hour Meters on Two-phase System.

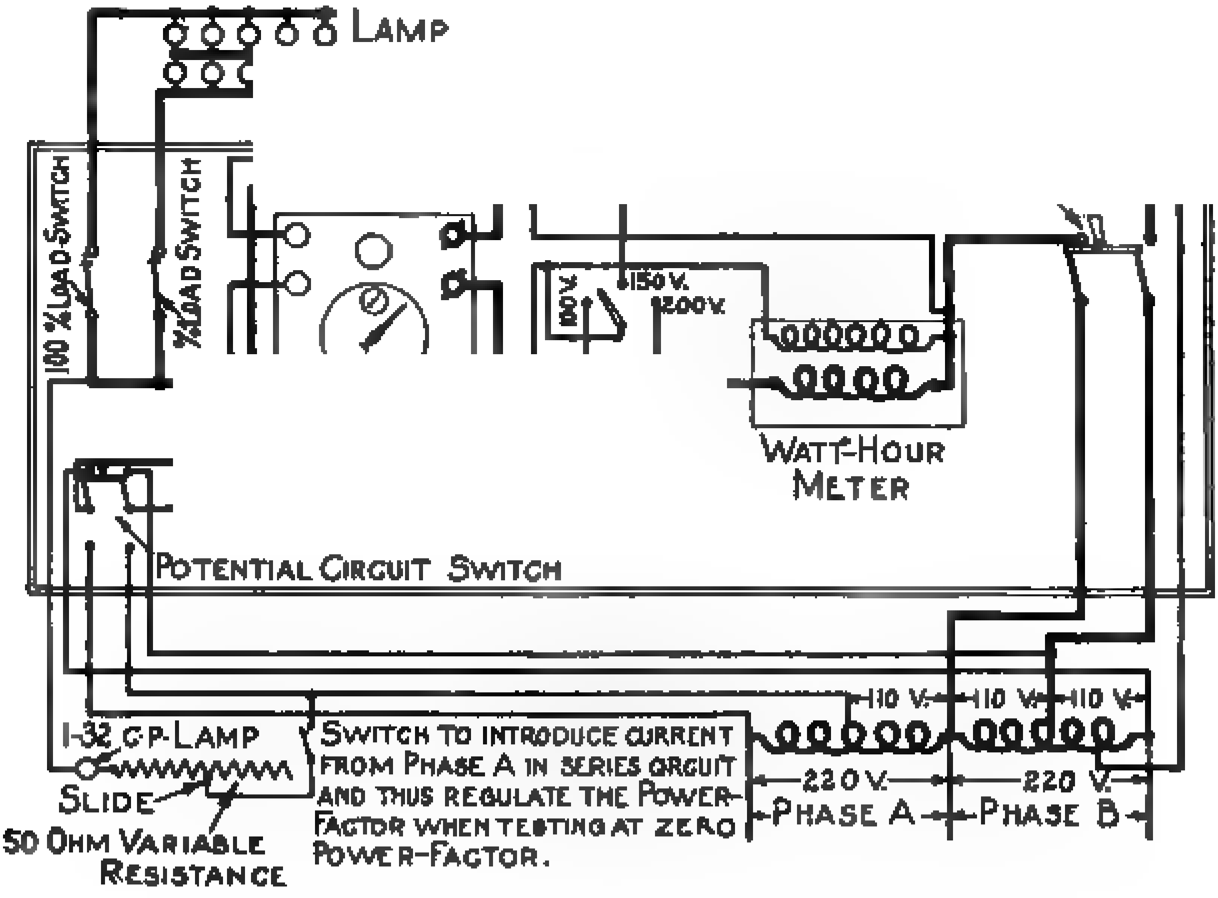


Fig. 227.—Diagram of Connections for Testing Single-phase Watt-hour Meters on Two-phase System.

ing exactly in quadrature. If the secondary standard shows any load the current should be further lagged by inserting a sufficient number of lamps in the phase *B* circuit (Fig. 226), or if desired, an inductance can be inserted in the current circuit of the watt-hour meter under test. In order to secure the proper phase relation it may in some instances be necessary to reverse the high-tension, or low-tension, connection of the transformer in phase *B*. When the phase dis-

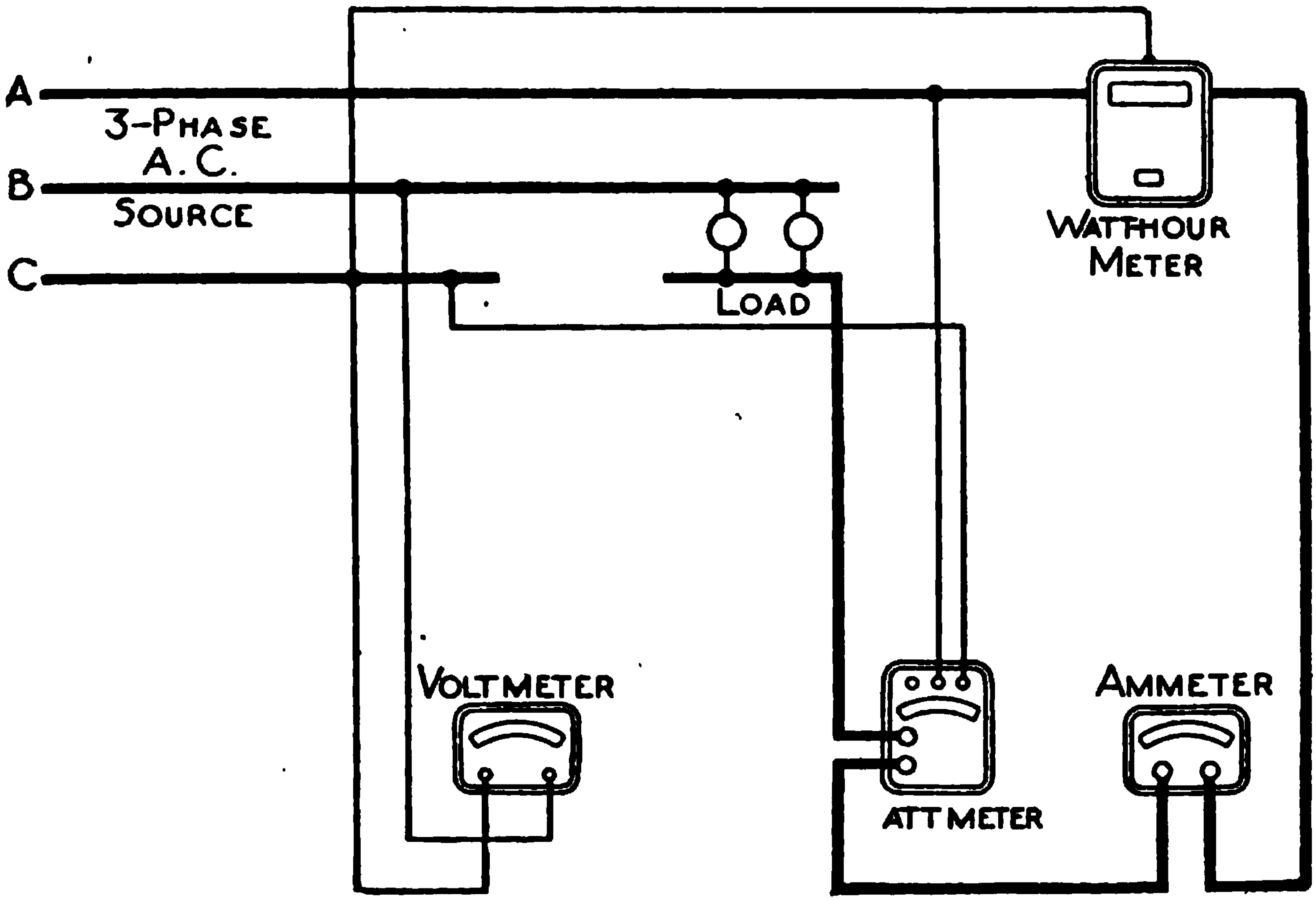


FIG. 228.—Diagram of Connections for Testing Single-phase Watt-hour Meters on Three-phase System at Power-factors of 1.00 and 0.5.

placement is exactly 90 degrees, the secondary standard should not show any load.

Fig. 227 is another diagram showing connections for testing single-phase watt-hour meter on single-phase and inductive loads.

Fig. 228 is a diagram of connections whereby, through the medium of the three-phase system, single-phase, alternating current, watt-hour meters can be tested at a power-factor of unity and of 0.5.

The condition of zero power-factor, or quadrature, may be also obtained from a balanced, three-phase circuit by connecting the watt-hour meter under test, as shown in Fig. 229, with the current coils in phase *A*, and connecting the potential element across phases *B* and *C*, the load

being placed between phases *AB* and *AC*. This load must be the same (balanced) on each phase to obtain the desired result. Other power-factors may be obtained by using unbalanced loads on the two-phases (Fig. 159, Chapter V).

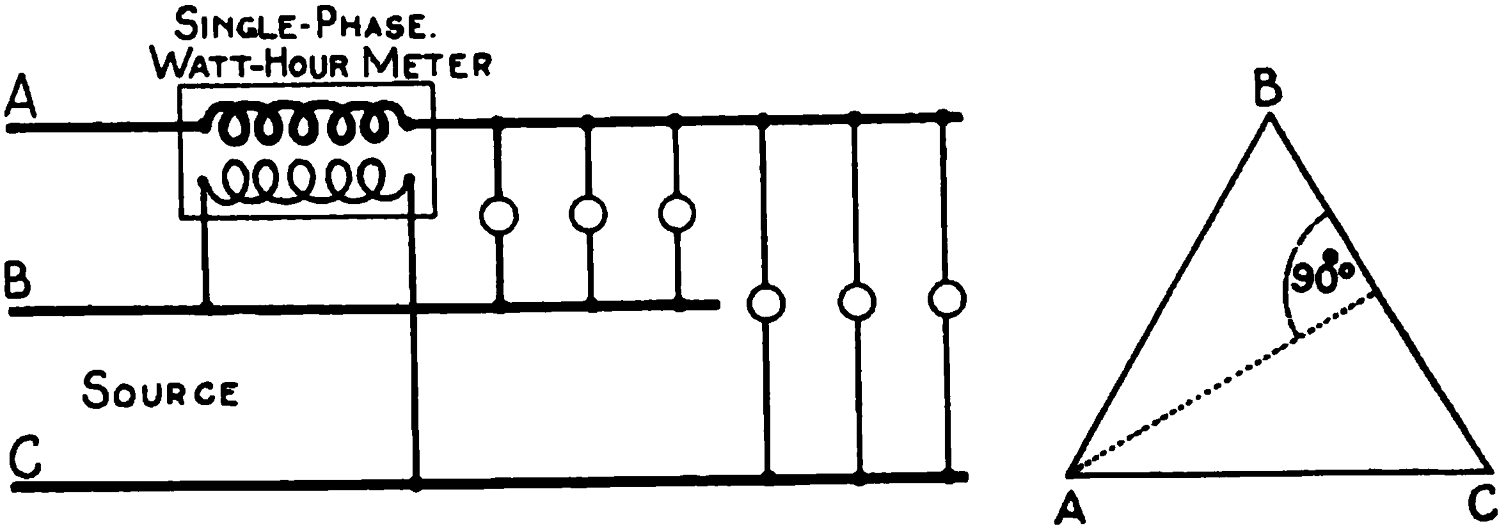


Fig. 229.—Diagram of Connections for Testing Single-phase Watt-hour Meters on Three-phase System at Power-factors of 0.

Another method of obtaining this condition from a three-phase circuit is to transform from three-phase to two-phase and connect the watt-hour meter under test into the two-phase circuit as shown in Fig. 230. This method necessitates the use of special transformers having the three-

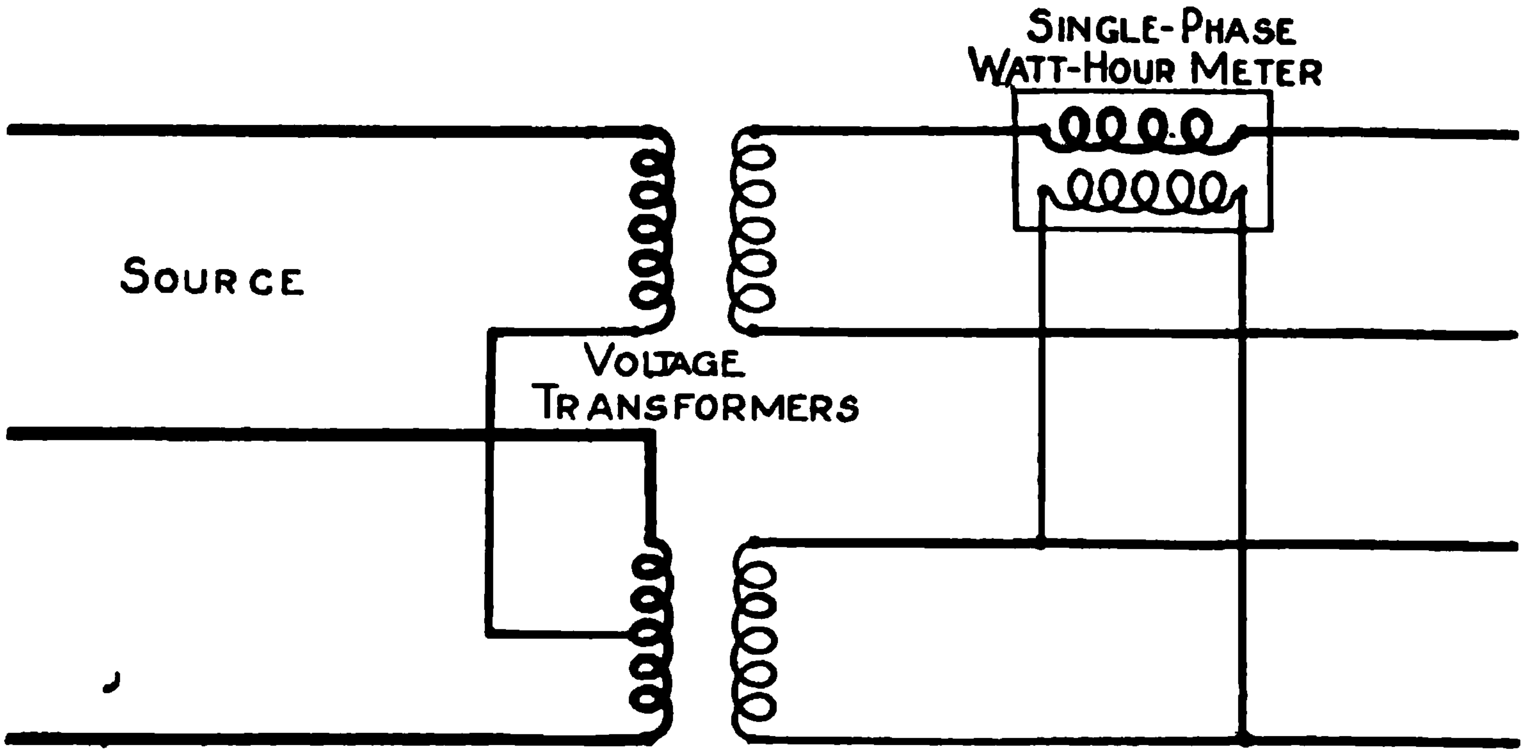


Fig. 230.—Diagram of Connections for Testing Single-phase Watt-hour Meters, at 0 Power-factor, on Two-phase System Obtained by Transformation from Three-phase System.

phase to two-phase connection, but in some cases this method may be more convenient than the method shown in Fig. 229, as it eliminates the necessity of maintaining the balanced load on the three-phase circuit, it being only necessary to have one lamp bank on one phase of the two-

phase circuit for a load. Having obtained a current in quadrature with the potential, the test should be conducted as outlined in the preceding paragraph describing the two-phase method.

Fig. 231 represents diagrammatically a watt-hour meter testing panel for testing one at a time, 5 and 10 ampere, alternating current, single-phase, two- or three-wire meters and polyphase meters, on a single-phase, the potentials of which operate at 230 volts.

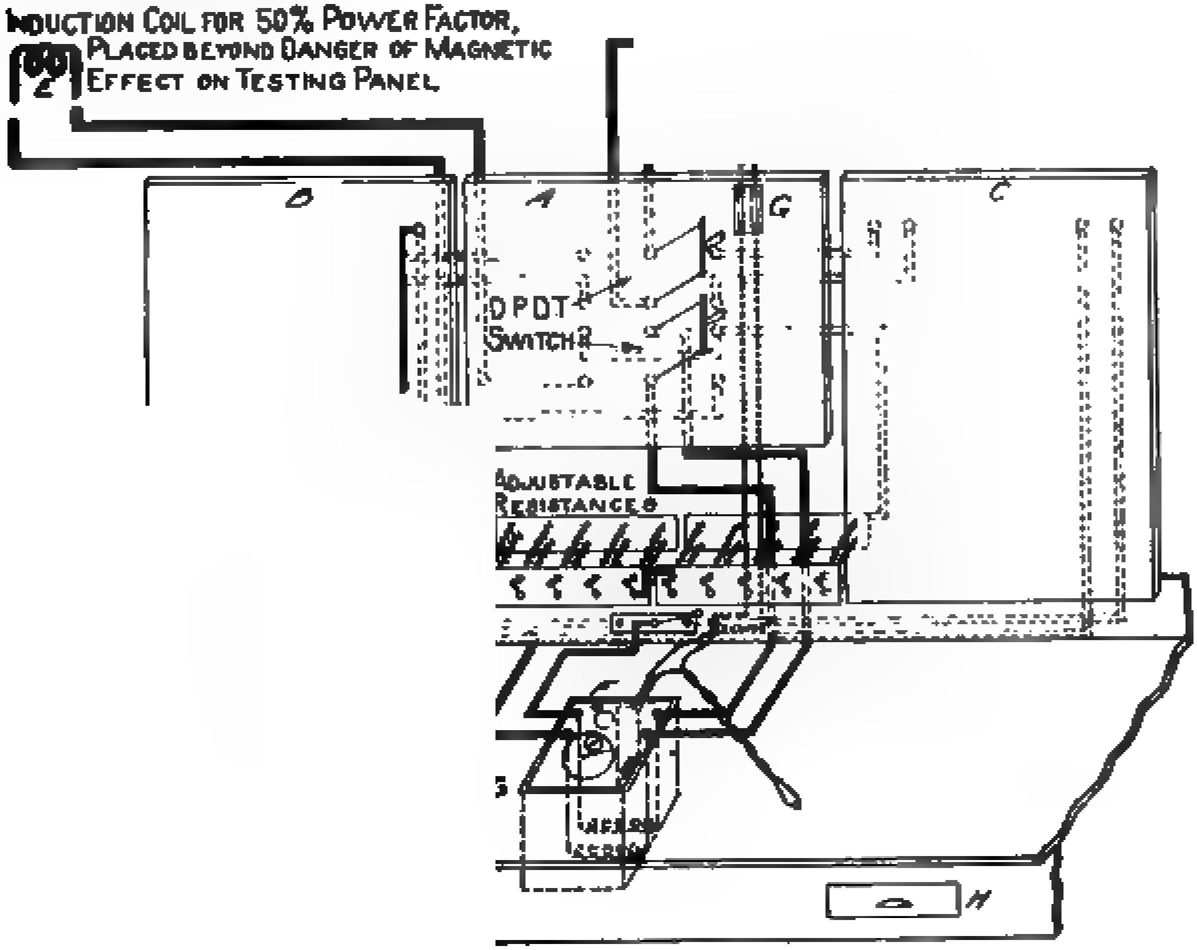


FIG. 231.—Separate Watt-hour Meter Testing Panel for Small Capacity, 230 Volt, Alternating Current Meters.

The duplicate arrangement of wiring and double throw switches is such that while one meter is under test on, say the left-hand panel, another may be being prepared for test on the right-hand panel, the wiring of which would be entirely disconnected. It would then be necessary only to throw the double throw switches to the right to transfer the test to the right-hand meter.

The rotating standard is mounted in the bench in front of the panel with its top flush with the top of the bench.

(*A*) is a marble switch panel, on which are mounted two double pole double throw switches. The upper switch will connect the system service to the outlets at either of the oak meter boards (*B*) or (*C*). The lower switch, when thrown to the right, will connect the non-inductive load of rheostat (*D*) through the rotating standard (*F*) to either watt-hour meter under test. When this switch is thrown to the left, the induction coil (*E*), mounted on wall, six feet above panel, will be connected in series with the rheostat giving an inductive load of 250

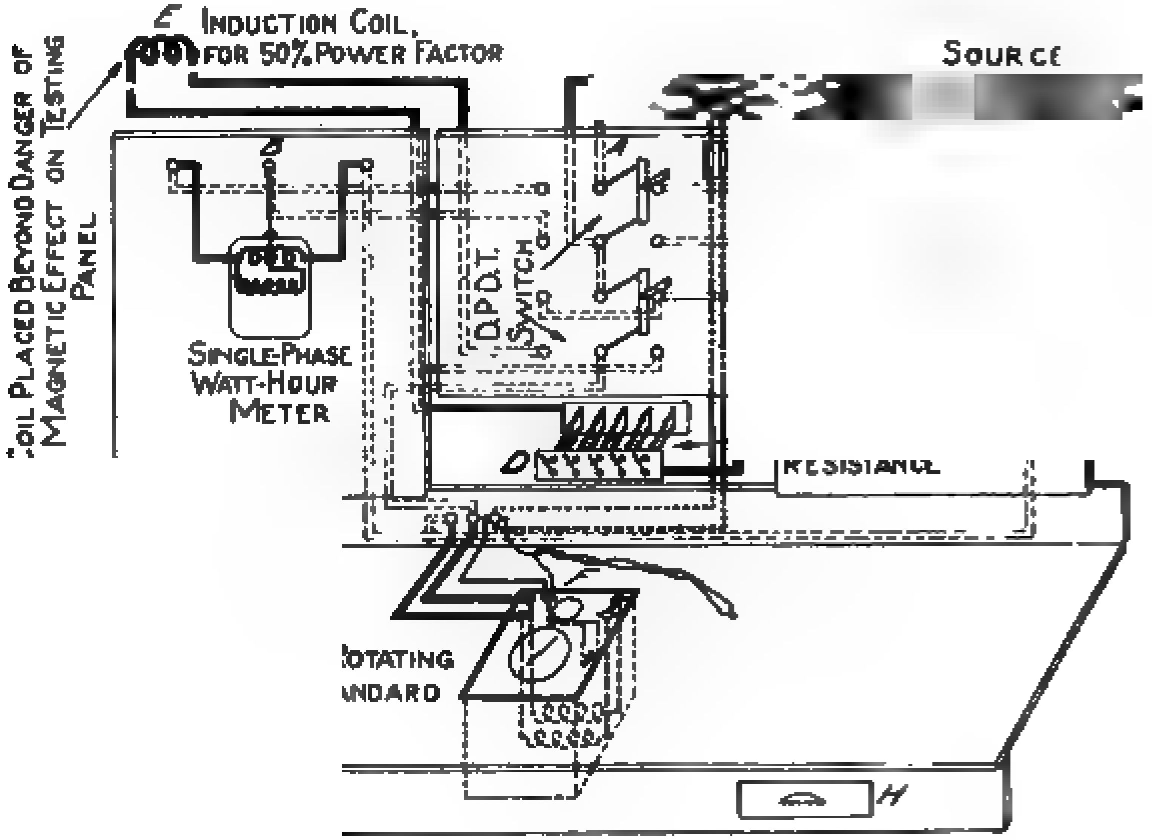


Fig. 232.—Separate Watt-hour Meter Testing Panel for Small Capacity, 115 Volt, Alternating Current Meters.

watts at .50 power-factor. The fuses for the voltage circuit of the rotating standard are shown at (*G*) and drawers for tools at (*H*) and (*H*). The rheostat is of the portable type, giving current in ⅛ ampere steps up to 15 amperes, but is permanently mounted.

Fig. 232 shows a similar panel to the above for testing alternating current watt-hour meters of 5 and 10 amperes capacity, at 115 volts.

Fig. 233 is another illustration of a typical watt-hour meter testing panel for continuous current, 5 to 50 amperes, 115 and 230 volt, watt-

The various features are enumerated below:

A. Marble panel.

B. Hinged slate watt-hour meter panel.

C. Rotating standard set into top of bench.

D. Low voltage watt-hour meter testing rheostat used when testing on battery service.

E. Lamp bank used when testing on system service.

F. Lamps used for light loads when testing on system service.

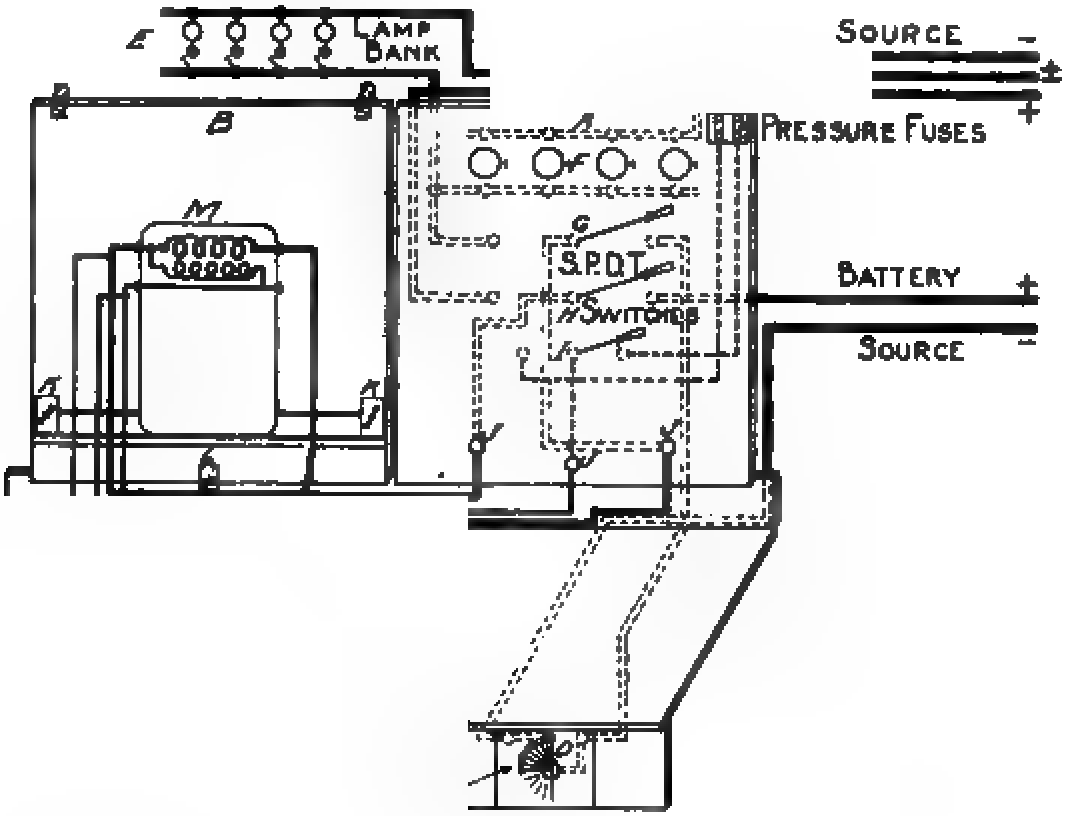


FIG 233.—Typical Watt-hour Meter Testing Panel for Continuous Current Meters, with Facilities for Testing from System Source or Battery Source.

G. Single pole double throw switch for connecting rheostat or lamp load, to watt-hour meter.

H. Single pole double throw service switch for connecting system service, or storage battery, source.

I. Single pole double throw pressure switch giving 115, or 230, volts; the positive sides of the battery and system services are tied together so that when testing watt-hour meters on battery current it is not necessary to have an additional pressure wire in the meter.

J. Binding post terminals for current leads.

K. Adjustable clamps in slot for holding Type M Thomson watt-hour meters.

FIG. 234.—Watt-hour Meter Testing Panel for Alternating Currents.
Fort Wayne Electric Works.

L. Leveling device with screw adjustment.

M. Hook for holding Type C Thomson watt-hour meters.

The watt-hour meter testing panel in Fig. 234 is equipped as follows:

First row: (*a*) handle for regulating inductive load; (*b*) ammeter; (*c*) load switch; (*d*) rotating standard; (*e*) voltage switch; (*f*) voltmeter; (*g*) hand wheel for fine adjustments of non-inductive load.

Fig. 235.—Watt-hour Meter Testing Panel for Alternating Currents. The States Company.

Second row: (*h*) switches for adjusting non-inductive load; (*i*) bell operated by rotating standard for indicating revolutions; (*j*) similar to (*h*).

Third row: (*k*) watt-hour meters under test: General Electric Company's Type I; Fort Wayne Electric Company's polyphase and Type K, and Westinghouse Electric and Mfg. Company's watt-hour meters.

Fourth row: (*l*) hand wheel to be used in conjunction with (*a*) for fine adjustments of inductive load.

This testing panel is made of slate and manufactured by the Fort Wayne Electric Company for use on alternating current.

Fig. 235 shows a 100-ampere watt-hour meter testing panel for use on alternating current at 110 or 220 volts. Space is provided on the panel for supporting any standard make of alternating current meter. A main switch and cut-out protects the panel; opening this switch disconnects the entire board.

A double set of potential binding posts is provided, so that potential connections to watt-hour meter and rotating standard can be

FIG. 236. -Potential Phase Shifter. The States Company.

made independently. Binding posts for the load current are located in such positions that connections to watt-hour meter and rotating standard may be made independently. A potential switch for the control of the rotating standard is provided for use, if desired. Selective switches at the top of the panel control the load current. These switches are arranged to give small gradations of load up to the rated capacity of the panel.

The method used for loading the watt-hour meter under test is that known as the phantom load method, by which the load current supplied to the current coils from a source of lower potential that of the circuit to which the meter potential element is con-

nected. A transformer having a small low-tension voltage and with a high-tension side which is connected to the ordinary low potential lighting supply source through the main switch, is mounted on the back of the panel. From the low-tension side, the load current is conducted to the selective switches, the controlling resistances, the watt-hour meter under test and the rotating standard. Provision is also made for adjustment of the power-factor through adjustable inductance by means of a hand wheel on the front of the panel.

This testing panel is made of slate and is manufactured by The States Company, Syracuse, N. Y.

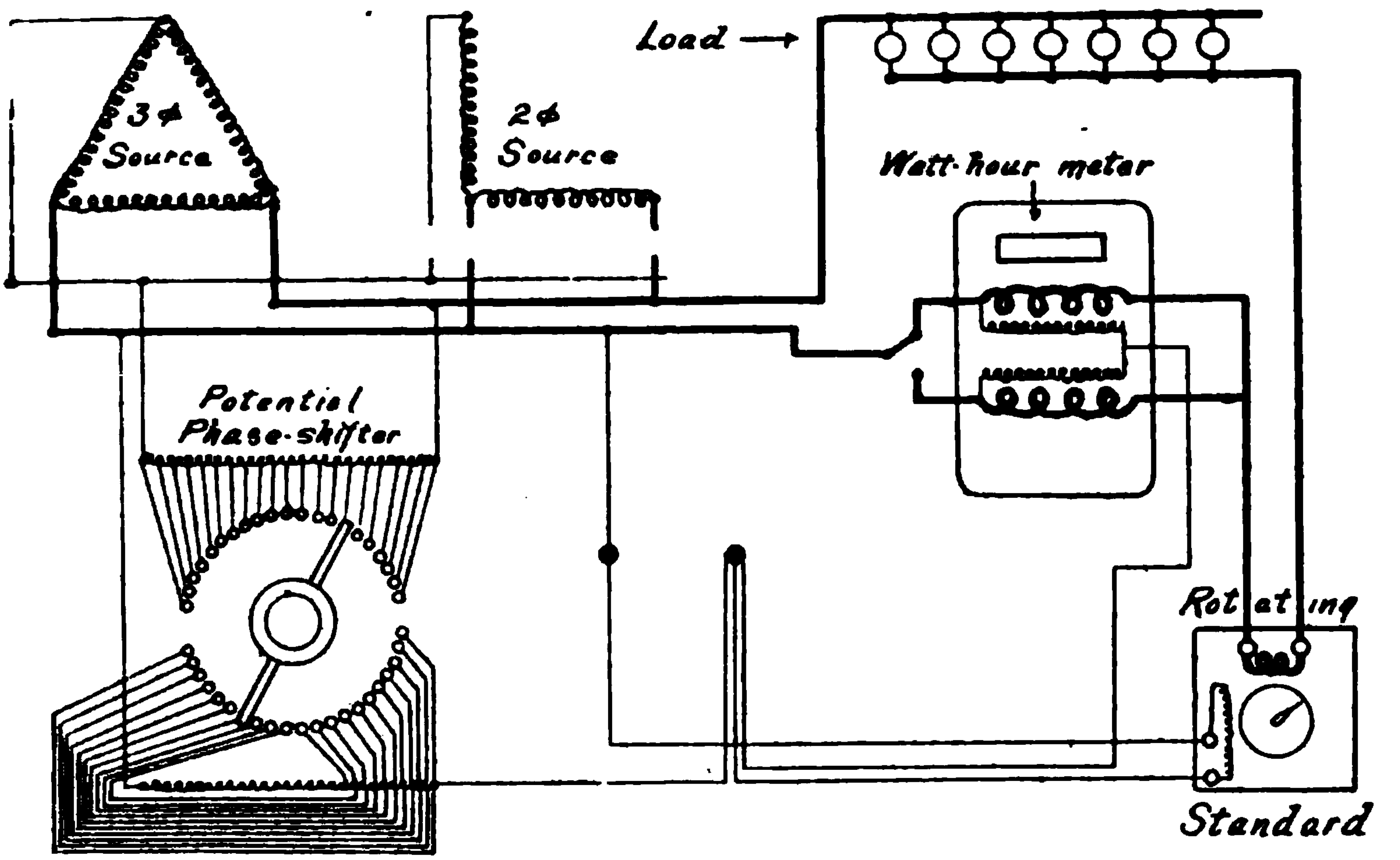


FIG. 237.—Diagram of Connections for One Potential Phase Shifter used on Two- or Three-phase Circuits.

The Potential Phase-shifter is an apparatus for producing any desired power-factor for watt-hour meter testing, using an ordinary non-inductive load, in the series coils (Fig. 236).

In order to determine the accuracy of registration of a watt-hour meter at any given power-factor, it is necessary to compare such registration with that of a rotating standard under that particular condition of phase relation between current and potential.

To make such a comparison, however, it is merely necessary to have the desired phase displacement and it is immaterial whether the phase of the current, or the phase of the potential is changed.

The usual way is to introduce an inductive load in combination with a resistance load into the path of the current in the series coil, thereby producing the desired phase displacement. It is usually difficult to get any large range of load at various power-factors by this means.

The potential phase-shifter is an apparatus for bringing about the desired phase relation between the current and the voltage impressed on the potential element by changing the phase of the voltage.

The operation of the potential phase-shifter depends upon the fact that two electromotive forces of different phases may be combined to form a resultant electromotive force having a phase unlike either of the components.

Where two electromotive forces of fixed value and phase are available, as in a normal two- or three-phase circuit, a third electromotive force may be derived having any desired phase.

The apparatus includes two auto-transformers. One is connected in one phase of a two- or three-phase circuit and is provided with a multiplicity of taps for obtaining different potentials in that phase. The other auto-transformer also has a multiplicity of taps and by connecting this between the third wire of the circuit and the taps of the first auto-transformer, electromotive forces of various phases are set up in the second auto-transformer. By using the proper taps of the second auto-transformer the value of the electromotive force is kept constant.

A dial switch is connected to the various taps of the two auto-transformers in such a way that by turning the switch handle a constant electromotive force of predetermined phase is obtained for each position of the dial switch. The apparatus is made in two forms, one producing phase changes from 0 degrees to 60 degrees from the phase of the current in the series coils, the other producing changes from 0 degrees to 90 degrees. The steps are arranged, not by equal lag angles, but by angles that give 5 per cent differences in the equivalent power-factor.

Fig. 237 shows **the connections** of a potential phase-shifter for use on a three-phase or a two-phase circuit and producing changes in power-factor from 1.00 to .50 by .05 steps. Lower power-factors are obtained by extension of the winding of the upper auto-transformer to the left, providing additional taps.

Changes in the current value through the series coil of the watt-hour meter do not affect the phase of the current in the potential element, as furnished by the phase-shifter, therefore the dial switch once set for a given power-factor holds that value over all loads.

An ordinary lamp bank, or other non-inductive load, should be used for obtaining the current through the series coil of the watt-hour meter,

or a watt-hour meter testing load panel, which provides a load having a power-factor of .99 to 1.00 may be used.

When a watt-hour meter has been set up and is ready for test, the dial switch should be set by merely turning the handle to the point marked with the power-factor desired. If then it is desired to test at another power-factor, the dial switch handle is turned to the point marked with that power-factor.

If two loads and two potential phase-shifters are used, different normal, or abnormal, conditions of operation on a polyphase watt-hour meter may be duplicated in the laboratory at will.

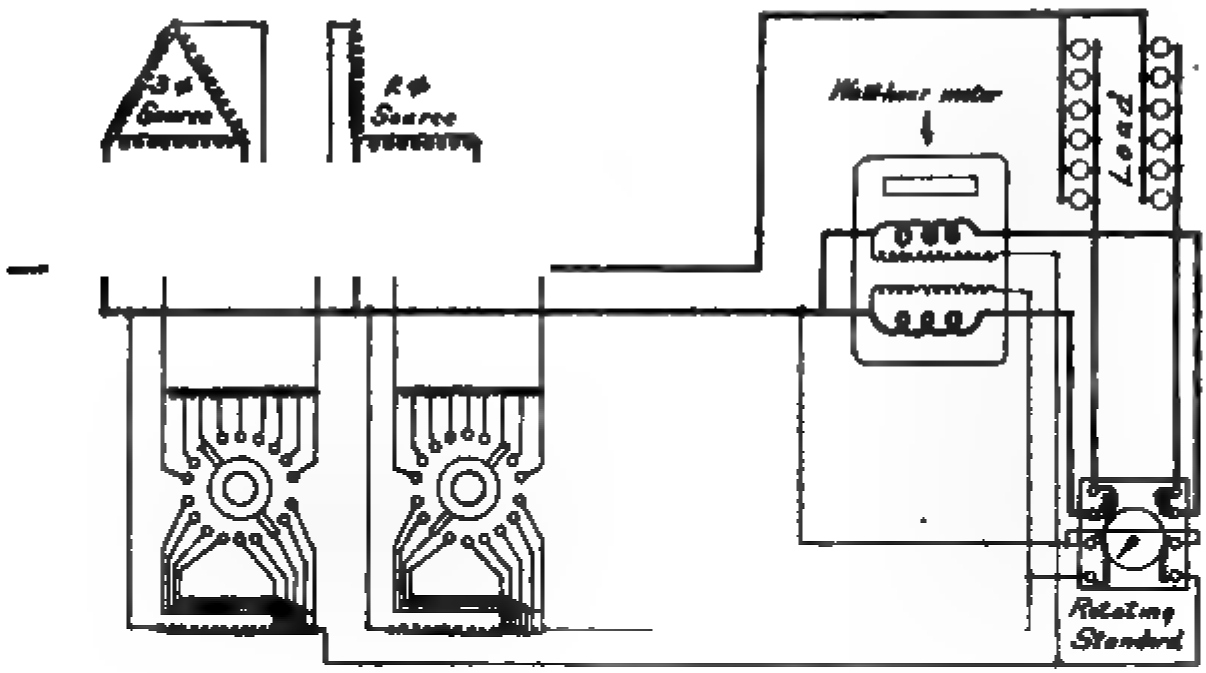


Fig. 238.—Diagram of Connections for Two Potential Phase Shifters used on Two- or Three-phase Circuits.

Fig. 238 shows one method of connection for using two of the potential phase-shifters with a polyphase watt-hour meter.

Fig. 239 shows a double load, watt-hour meter testing panel using low voltage loads and two phase-shifters.

The potential phase-shifter is manufactured by The States Company, Syracuse, N. Y.

The repair room is frequently combined with the testing room, as the two classes of work can be advantageously carried on together. Systematizing the repair work as well as all other branches of the department, is essential to economical operation. "Have a place for everything, and have everything in its place."

There should be provided a good solid work-bench with vises and a full

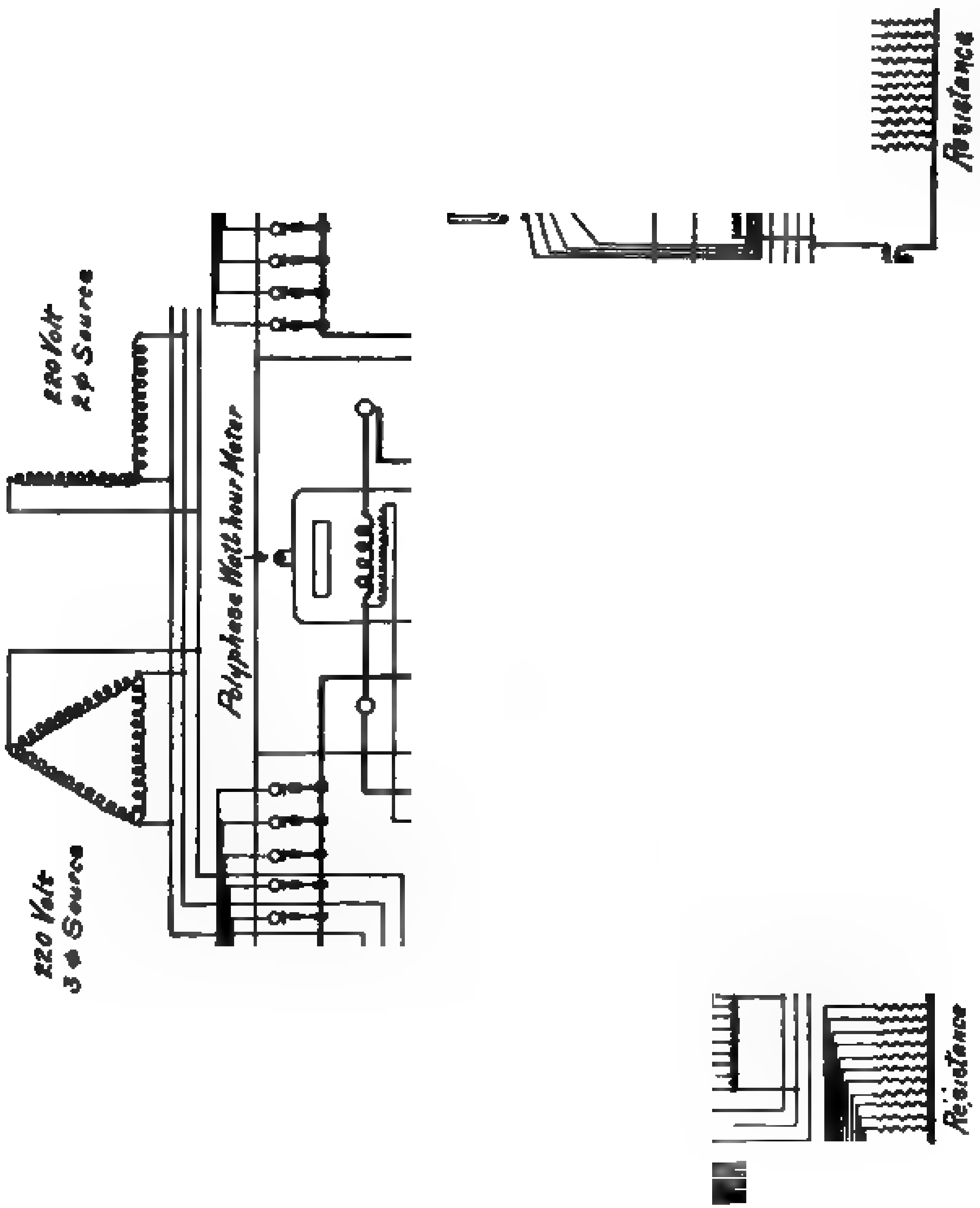


FIG. 239.—Diagram of Connections for Double Load Watt-hour Meter Testing Panel, Using Two Potential Phase Shifters.

equipment of necessary tools, including hack-saw, brace and bits, hammers, files, pliers, wrenches, screw taps and dies. A precision lathe and

small capacity drill press are also desirable. There should be a material cabinet of sufficient size to keep a complete assortment of repair parts for all the watt-hour meter types in use. By keeping an assorted stock plainly labeled and reordered as used, much time can be saved in making repairs and a smaller stock of meters will be necessary than if the defective meters were stored, awaiting the arrival of repair parts which were not ordered until needed. It has been found to be economical to purchase most repair parts from the manufacturer, especially when consideration is given to the extra time required in readjustment, if the

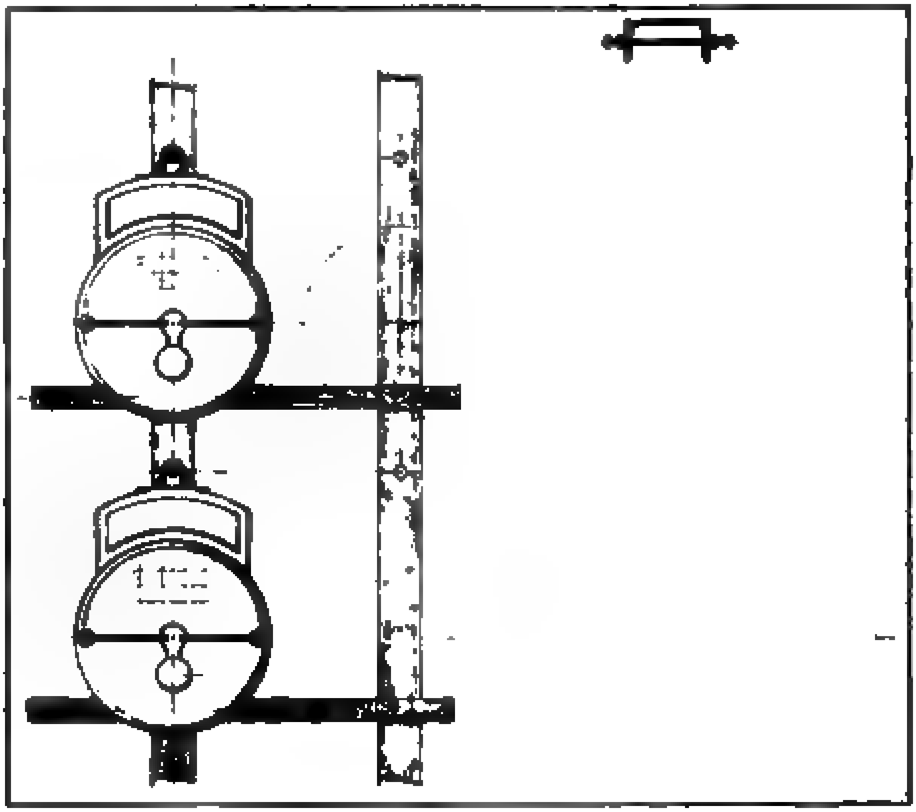


FIG. 240.—Meter Storage Rack.

parts are made up and found to be a trifle out of standard. A low box with a number of compartments has been found convenient for holding dissembled watt-hour meter parts so as to prevent their loss or interchange. A long table, or bench, should be provided for cleaning and numbering watt-hour meters.

The stock room should if possible be located near the testing room, and a small truck will be convenient for transferring the watt-hour meters. The meters should be stored on shelves or racks, providing separate sections for tested and untested meters, and keeping the various sizes and types segregated. A scheme of rack construction which has proved very economical in space is illustrated in Fig. 240.

The watt-hour meter assigned to each installation should be suited to the voltage, frequency and character of the circuit and should be chosen with a view to obtaining the best adaptation to the local condition and to the load. It is not advisable to use commutator meters on alternating circuits. Unlagged meters should never be used on inductive loads.

While it is possible to meter polyphase circuits accurately with single-phase watt-hour meters, yet it is preferable to use polyphase meters, because the installation is simplified; only one register reading is required, and complaints by the consumer that the two single-phase meters do not register equal amounts are eliminated.

An objection advanced against polyphase watt-hour meters is that if one potential circuit opens it is not readily detectable, since the meter will continue to operate, although inaccurately.

It may be assumed as axiomatic that it is never advisable to install a **watt-hour meter** of greater **capacity** than is necessary to efficiently and economically register the load on which it usually operates. Over-metering not only increases the investment in meters, but results in an actual loss of revenue due to light load inaccuracy, as a watt-hour meter of small capacity will register a small load more efficiently than will a meter of larger capacity; the general tendency of watt-hour meters being to run slow, especially on light loads.

Watt-hour meters are generally most accurate when operating between 25 and 125 per cent of their rated current capacity. The meters for a given installation should be so chosen that the average load comes well within these limits and as near to its rated capacity as is possible without danger of damaging it or impairing its accuracy. Where the maximum load is of very short duration or occurs only at rare intervals, the preference should be toward smaller capacity meters. If, however, the duration of the light load is short compared with that of the heavy load, the watt-hour meter should be chosen to give the best accuracy under the latter conditions.

The connected load is generally taken as the sum of the ratings of all the apparatus connected to the circuit. The percentage of the connected load which is in use at any time is dependent upon the character of the installation and the business of the consumer, and it is at this point that the greatest uncertainty is encountered in choosing the proper size of watt-hour meter. In large installations, the question may be settled by a study of individual cases, but for small installations it is necessary to adopt general rules for various classes of consumers.

In the larger installations, local conditions frequently require special

consideration to secure the most efficient results. The purpose for which the building is to be used and the business of the consumer are important factors, as the percentage of connected load used will vary largely, depending upon these factors.

Some companies decrease to some extent the difficulties of accurately metering an installation by limiting the character of the load to be connected to the same main and watt-hour meter; as, for instance, separate meters are required for light and power circuits; separate meters are required for signs, photographic arcs, charging sets, and other constant loads in excess of certain limits; separate meters are required for arc and incandescent lighting where the combined load requires a watt-hour meter larger than will start on one 16 candle-power lamp, and so on.

While usual practice shows that on the average the kilowatt capacity of the watt-hour meters about equals the kilowatt capacity of the connected load, yet this is no doubt due to the large number of small capacity watt-hour meters installed on very small capacity installations; as for instance, a 5 ampere watt-hour meter installed on two desk fans, or two or three lights. Such installations are of course greatly overmetered, but this is permissible for the reason that it is poor economy to purchase a meter of smaller capacity than 5 amperes.

In residences and apartments, watt-hour meters rated at from 35 to 50 per cent of the connected load should generally be used, as seldom more than 50 per cent of the lamps installed are used at any one time. Occasionally, during social, and similar functions, the meters must withstand a large overload, but the losses due to these overloads, which are usually infrequent, are more than compensated for by the greater accuracy obtained on the normal load. Most modern meters will withstand at least 100 per cent overload without burning out.

Ordinary stores require meters rated at about 75 per cent of the connected load, but large wholesale houses, where the lights are in use only when exhibiting goods, should be treated similarly to residences. It is not, however, customary to use watt-hour meters of lower than 5 amperes rating.

In small stores, saloons and similar places, where all the lamps connected are usually burning at one time, a watt-hour meter should be installed having a capacity about equal to the connected load. If, however, a certain number of the lamps are burned all night, it may be desirable to install a watt-hour meter of less capacity, the determining factor being the losses due to overload for a few hours considered against the losses due to light loads for the longer period.

An examination of the amount registered per month is sometimes an indication of the capacity of watt-hour meter to be installed. Such an

examination may show that it is advisable to replace a meter by one of greater, or less, capacity.

Where the load is practically constant, such as in restaurants, saloons, stores where all of the lamps are used at one time, signs without flashers and moving picture arcs (when metered separately from the auditorium lights), the capacity of the watt-hour meter should be approximately equal to the connected load.

For single motors the meter capacity is usually equal to the current rating of the motor. For elevator and crane motors, and for motors that are started and stopped frequently, some companies consider that the watt-hour meter should have a capacity of 25 or 50 per cent greater than the nominal horsepower of the motor; in some instances even greater, depending upon the starting current and duty of the motor. When several motors are connected through the same watt-hour meter, the diversity factor of the load often is such that a meter rated at much less than the combined ampere capacities of the motors may be used.

It may frequently be found advisable, after an installation is made, to determine the maximum and minimum demand, and to change the watt-hour meter, if necessary, to a greater or smaller size.

In large installations it may sometimes be advantageous to subdivide the load, metering the various divisions independently. Small loads of long duration should be metered separately from large loads of short duration. Two or more loads whose maximum values are equal but occur at different times may advantageously be combined on one watt-hour meter. Two or more loads of unequal value may also be combined, provided that the smaller load is never used without the larger. In some cases, however, on account of the diversity factor of the installation, the average percentage of full load at which the meters operate will be reduced rather than increased by subdividing the installation, in which case a single meter should be used.

In churches, theaters, department stores, factories, et cetera, separate watt-hour meters may advantageously be installed for the large number of lights used occasionally and the smaller number used for cleaning, et cetera, as it is generally impossible to install a single watt-hour meter that will be of sufficient capacity to measure the maximum load and efficiently measure the minimum load. In such cases the circuits should be divided, and several watt-hour meters should be installed. For instance, in such buildings it is customary at times through the day, and during the hours of cleaning, to use only a very small percentage of the lamps, and to endeavor to measure the current used by these lamps with a watt-hour meter of sufficient capacity to measure accu-

rately the entire installation, involves a loss that can usually be saved by using separate circuits and two or more smaller watt-hour meters.

Aside from the question of accuracy of metering, the subdivision of the installation has the advantages that the consequences of failure or error in a single meter are lessened, less special equipment for testing is needed, and reasons for fluctuations in the bills are most easily determined. Its disadvantages are that the investment and the labor of testing, reading and billing are, on the whole, increased, and that on account of the diversity factor of the installation, the smaller watt-hour meters must have a greater aggregate capacity than would be required in a single meter for the whole installation.

In very large installations which are metered as a single circuit, it is sometimes found advantageous to connect several watt-hour meters in parallel, instead of using a single meter of large capacity. Especial pains must be taken to insure equal resistances in the various current circuits to prevent overloading any of the meters.

Watt-hour meters must be handled carefully at all times. They are instruments of precision. The greatest care has been exercised in their design and manufacture by their makers, and to retain this condition they must be considered as delicate instruments and treated as such at all times.

The routine of handling followed in specific cases depends greatly on local conditions. Suggestions which would apply to small companies might not be feasible for the larger ones. Therefore, it must be left to the management to apply the suggestions. After the watt-hour meters have been received from the manufacturer, and checked with the order, by the general stock room, they should be in the custody of the meter department, although it is the practice in some companies to return them to the custody of the general stock room after being tested, and to issue them therefrom upon requisition from the installation department. Where space will permit and the watt-hour meters are in the modern individual cartons, it is found better to unpack them only as needed, thereby saving both handling and extra storage shelves.

New watt-hour meters should be unpacked with care and given a general examination for damage in transportation, marked according to the company's method of identification and entered in the stock records.

They should be carefully examined for any mechanical defects that will prevent their proper operation. The constants should be checked, and the insulation should be tested to see that none of the circuits are grounded on the meter frame, and other inspections should be carefully made. They should be tested and calibrated on the standard loads to ascertain

that the meter can be properly adjusted. Induction watt-hour meters should be tested to ascertain if they are properly lagged and will register accurately on non-inductive loads, and also on inductive loads of 0.50 to 0.70 power-factor.

In this case of new meters, readings for accuracy should be taken as a check on the manufacturer and to disclose injuries received during transportation.

The meters should be carefully examined to detect defects and errors in manufacture and to insure that all mechanical parts are in proper adjustment.

Watt-hour meters returned from service should be treated substantially as are new meters, and, in addition, each one should be thoroughly overhauled and put into a state of repair equal to that of a new meter.

In the case of watt-hour meters returned from service it is desirable that register readings and readings of accuracy "as found" be taken before any changes are made in the meter. These readings, if taken, should be recorded for use in settling possible complaints involving the time between the last test of the meter and its removal.

There are several methods in use for **numbering watt-hour meters.** Every company will find it advantageous to number its watt-hour meters serially. Some companies use the manufacturers' numbers, but this system is objectionable, as the numbers are not consecutive so far as the individual company is concerned. The simplest method of serially numbering watt-hour meters is, of course, to number them from 1 up, irrespective of the make, capacity and other characteristics, but this system does not have the advantage of describing the meter. Some companies, therefore, have adopted a designating system of numbering, examples of several of which follow.

The number may consist of two parts, separated by a letter which indicates the make or name of the meter. This first part of the number indicates the capacity of the watt-hour meter in amperes and volts, and also whether it is two- or three-wire. The second part is the serial number proper, each size of each make of the meter being numbered serially from 1 up.

The first part of the number, which may be called the capacity number, always consists of three figures, except in the case of three-wire meters, which are all of 220 volts; therefore the number corresponding to the voltage is omitted. The voltages and number designating each are as follows:

100	represents	100–124 volts,
200	"	200–240 volts,
300	"	500–600 volts.

The letters designating the make or name of the meters are as follows:

K	represents	Fort Wayne Type K watt-hour meters,
T	"	Thomson Recording wattmeters,
W	"	Westinghouse watt-hour meters.

The ampere capacities of all numbers manufactured are arranged in numerical order and are numbered consecutively from 1 up. The ampere capacity of the watt-hour meters and the corresponding capacity numbers for the different voltages are as follows:

Capacity Number	Amperes Capacity	Two-wire, 110 Volts	Two-wire, 220 Volts	Three-wire, 220 Volts
1	3	101	201	1
2	3½	102	202	2
3	5	103	203	3
4	7½	104	204	4
5	10	105	205	5
..	....	...	...	..
..	....	...	...	..
..	....	...	...	..
..	....	...	...	..
15	100	115	215	15

For example, 105-K-12 represents 110 volt, two-wire, 10 ampere, Fort Wayne Type K watt-hour meter No. 12.

203-T-22 represents 220 volt, two-wire, 5 ampere Thomson Recording Wattmeter No. 22.

For preserving a record of the meters a card index is used. Cards having the same capacity numbers are filed together serially for each make of meter, the different capacity numbers being separated by guide cards. The cards are arranged under the headings "Meters in Service," "Meters in Stock" and "Meters Ordered," and by this means the total number of every size and make of meter in service, in stock and on order can be readily determined within a few minutes.

Another method of numbering watt-hour meters in use is as follows:

KEY TO WATT-HOUR METER NUMBER SYSTEM

Co's Type	Capacity in Amperes 5	10	20	40	80	120	150	200	300	400	Wire and Volts	Mfr's Type	Public Service Group
A	1	2	3	4							2-100	B	20
B	1	2									2-100	A	20
C	1	2	3								2-100	C	20
D	1	2	3	4							2-100	CD	20
E	1	2	3	4					9		2-100	CE	20
F	1	2	3	4	5	6	7	8	9	0	2-100	CF	20
*G	1	2									2-100	OA	40
H													
I								8		0	2-100	CQ	1
J	1										2-100	I-10	30
K													
L													
M	1	2	3	4							3-100	B	20
N													
O	1										3-100	C-6	1
P	1	2	3	4							3-100	C	20
Q	1	2	3	4	5	6	7	8	9	0	3-100	CF	20
R	1	2	3	4	5						3-100	CD	20
*S	1	2									3-100	OA	40
T	1	2	3	4	5						3-100	CE	20
U	1	2									3-100	OA	40
V													
W													
X													
Y		2	3	4	5	6	7	8	9	0	PP-200	CA	50
YY				4	5						PP-100	CA	50
Z		2	3	4	5	6	7	8	9		PP-200	CB	50
ZZ				4	5						PP-100	CB	50

*Bottom connected.

In using this method, the order of designation will be: first, type; second, current capacity; third, serial number. The type letter in this case will show the Public Service group and manufacturer's type, voltage and wire.

For example: number A 1123 would represent a Type "A" meter belonging to Group 20 of approved watt-hour meters, the meter being the Westinghouse type B, 110 volts, two-wire; the first figure 1 means that the capacity is five amperes, and 123 is the serial number. This

system, when it can be applied, it is believed, will greatly facilitate the work in all of the departments having to do with the watt-hour meters. It is sometimes required to change a meter for some reason, and it is important that the meter be replaced with one of the same size and type. This is particularly true where watt-hour meter connection boxes are in use (Chapter XIV). It is ordinarily necessary to get this information over the telephone from the meter department, or from some other record. By means of the above scheme, as comparatively few sizes and kinds of watt-hour meters are handled, one will soon become familiar with the designating letter and figure, so that it will not be necessary to refer to any record. In order that the two-wire meters may be distinguished from the three-wire meters, different classes have been given letters in certain sctions of the alphabet, as indicated in the table.

Some companies that have a very large number of meters find it convenient to use an embossing machine for stamping serial num-

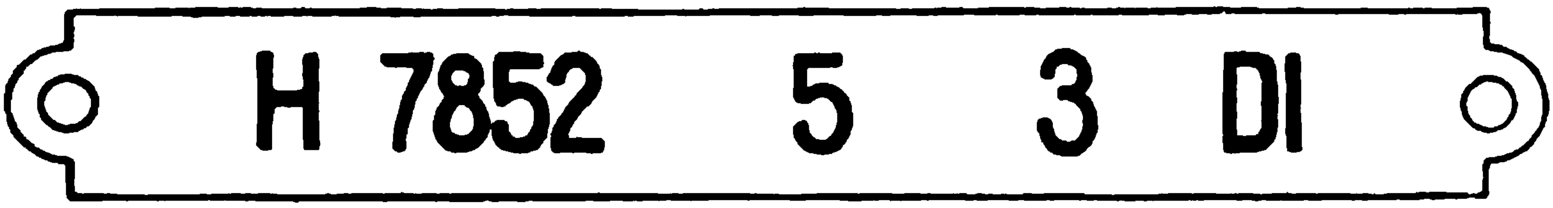


FIG. 241.—Aluminum Numbering Plate for Watt-hour Meters.

bers on a strip of aluminum, which is then riveted to the watt-hour meter cover. Other companies use a brass tag; others merely stencil the number on the cover, while still others print the number on a strip of paper, which is shellaced on to the cover.

It might be necessary to paint the serial number on the inside of the meter to insure against the cover being placed on the wrong meter.

One company who uses these aluminum strips for labeling has devised the following designating system of numbering:

Notation for aluminum name plates for watt-hour meters: Fig. 241.

The first designation, the manufacturer and type, is by a letter, or letters, viz.:

H, for General Electric, 60 cycle, single-phase, induction meters, Type I.
S, for General Electric, 25 cycle, single-phase, induction meters, Type I.
Hx, for General Electric, 60 cycle, single-phase, induction meters, Type I-10.
P, for General Electric, 60 cycle, polyphase, induction meters, Type D-3.
WH, for Westinghouse, 60 cycle, single-phase, induction meters, Type C.
WHO, for Westinghouse, 60 cycle, single-phase, induction meters, Type OA.

WS, for Westinghouse, 25 cycle, single-phase, induction meters, Type C.
WP, for Westinghouse, 60 cycle, polyphase, induction meters, Type C.
WSP, for Westinghouse, 25 cycle, polyphase, induction meters, Type C.
R, for General Electric, Commutator Type M meters, rebuilt by company.
C, for General Electric, Commutator Type C, C-6, C-7 or CQ meters.
CS, for General Electric, Commutator Type CS, switchboard type.
E, for General Electric, Commutator Type E, switchboard type.

The second designation, the company's number, is by a number,

3 digits starting with 101 for Form S, FI, JE-3, GE, polyphase GE Type D-3 and Westinghouse polyphase Type C.
4 digits starting with 1,001 for Form J, JN, F, FN, J-3, D-3, RBI, GE and CS, C, CQ, C-6, C-7 Commutator meters and GE Type I and Westinghouse Type C single-phase induction meters.
5 digits starting with 10,001 for Form J-2, D2, I-10 and rebuilt T. R. wattmeters.

The third designation is the current rating, by a number, viz.:

5 for nominal rating of 5 amperes.
10 for nominal rating of 10 amperes, et cetera.

The fourth designation, the voltage and number of wires, is by a number, viz.:

1 for nominal 100-110 volt, two-wire 1 ϕ, or 100-110 volt polyphase meters.
2 for nominal 200-220 volt, two-wire 1 ϕ, or 200-220 volt polyphase meters.
3 for nominal 200-220 volt, three-wire 1 ϕ meters.
4 for nominal 400-440 volt, two-wire 1 ϕ, or 400-440 volt polyphase meters.
5 for nominal 550-volt, two-wire 1 ϕ.

The fifth designation, the kind of a register, is by a letter, viz.:

A for 5 hand non-direct reading register, in watt-hours.
B for cyclometer dials on R.B.I. meters.
C for cyclometer dials on all other meters.
D for 4 hand direct reading register, in kilowatt-hours.

The sixth designation, the register constant, is by a number, viz.:

1 for register constant of 1
2 for register constant of 2 or ½
4 for register constant of 4 or ¼
10 for register constant of 10, etc.

NOTE: Current transformers supplied with watt-hour meter by maker shall have same name plate as watt-hour meter itself.

Watt-hour meters used with odd current transformers should be name-plated as though no transformers were used.

Still another method follows:

KEY FOR SERIALLY NUMBERING ELECTRICITY METERS

Column No. 1			Column No. 2		Column No. 3		
1.	3	amperes	A. Copper Disk	G E	(0.) Two-wire,	55	volts
2.	3½	"	B. Aluminum Disk	"	(1.) " "	110	"
3.	5	"	C. Type C	"	(2.) " "	220	"
4.	7½	"	D. Type C-6 & C-7	"	(3.) Three-wire,	220	"
5.	10	"	E. Duncan		(4.) Two-wire,	440	"
6.	15	"	F. Sangamo Mercury		(5.) " "	550	"
7.	20	"	G. Columbia				
8.	25	"	H.				
9.	30	"	I.				
10.	40	"	J.				
11.	50	"	K. Type K Ft. Wayne				
12.	75	"	L. " K1 " "				
13.	80	"	M. " K2 " "				
14.	100	"	N. " K3 " "				
15.	120	"	O. Not in use				
16.	125	"	P. Type K4 Ft. Wayne				
17.	150	"	Q.				
18.	200	"	R. Westinghouse CD				
19.	300	"	S. " CE				
20.	400	"	T. " CF				
21.	450	"	U. Gen. Elec. Type I				
22.	600	"	V. " " " I-10				
23.	800	"	W.				
24.	1,200	"	X. Westinghouse OA				
			Y. Polyphase (3)				
			Z. Miscellaneous A C				

The numbers in Column No. 1 stand for ampere capacity; the letters in Column No. 2, make and type, and the numbers in Column No. 3, for the voltage and whether two- or three-wire.

There are four sections to the meter number.

In forming the meter number the proper number is selected from

Column No. 1, the letter from Column No. 2, the number from Column No. 3. The fourth section of the number is selected as follows:

For any combination of the above mentioned three columns, the watt-hour meters are numbered consecutively, starting at 1.

For examples:

11 C 3 91 is a 50 ampere, G. E. Type C, three-wire, 220 volt and 91st meter.

3 P 1 2 is a 5 ampere, Ft. Wayne, Type K4, two-wire, 110 volts, and 2d meter.

11 YU 3 1 is a 50 ampere G. E. polyphase three-wire, 220 volts, and 1st meter.

NOTE: In practice there is no spacing in the number.

Another method is in use where many types of watt-hour meters are utilized, a number of which bear a register constant, oftentimes a fraction, such as ½, or $^1/_5$. The older types may also read in parts of kilowatt-hours, say in hectowatt-hours. The numbers are riveted through the cover and consist of a zinc strip, blue in color, with raised figures from which the color has been removed. The types of watt-hour meters are first divided into six classes, represented by the following letters:

K represents meters having 4 dials and reading in kilowatt-hours, K being the initial letter of kilowatt-hour.

M represents meters having 4 dials and reading in kilowatt-hours, but which are power watt-hour meters; hence the letter M, which is the Roman numeral for 1,000, representing the kilowatt-hour.

S represents meters having 4 dials and reading in kilowatt-hours, but which are single-phase power watt-hour meters, and for this reason are designated by the letter S, the first letter of the word single.

T represents meters having 5 dials and reading in watt-hours, but which are three-phase power watt-hour meters, and for this reason are designated by the letter T, the first letter of the word three.

C represents meters having 5 dials and reading in hundreds of watt-hours, hectowatt-hours; hence the letter C, which is the Roman numeral for 100, representing the hectowatt-hour.

D represents meters having 5 dials and reading in watt-hours, but which are "direct current" power watt-hour meters, 500 volts, and for this reason are designated by the letter D, the first letter of "direct," also the Roman numeral for 500, the voltage of the meters.

After the above classification by letters further classification is made by numbers, and this is so arranged that of those watt-hour meters bearing register constants, a verification of that constant may be made at a glance.

The older types, Class C, watt-hour meters, which have the greatest variety of register constants, are numbered as follows:

Numbers up to 1,000	denote $K_r =$	$\frac{1}{4}$
" between 1,000 & 1,500 (note 1 & 5)	" " $=$	$\frac{1}{3}$
" " 1,500 & 2,500 (note 1 & 2)	" " $=$	$\frac{1}{2}$
" " 2,500 & 5,000	" " $=$	0
" begin with 5,200 (note the 2)	" " $=$	2
" " " 5,400 (" " 4)	" " $=$	4
" " " 5,600 (" " 6)	" " $=$	6
" " " 5,800 (" " 8)	" " $=$	8
" " " 6,000 (" " odd figures)	" " $=$	10 & 12
" " " 6,500 (" " " ")	" " $=$	20
" " " 6,700 (" " " ")	" " $=$	100

This table may be memorized and the register constants verified.

The D class of watt-hour meters is numbered on the same plan:

Numbers beginning with 7,000	denote $K_r =$	1
" " " 7,200	" " $=$	2
" " " 7,500	" " $=$	5
" " " 7,700	" " $=$	10
" " " 7,900	" " $=$	20

The other four classes bear register constants of 10, or a multiple of 10. usually 100, and are numbered as follows:

For class K watt-hour meters—

Numbers beginning with 40,000	denote $K_r =$	100
" " " 50,000	" " $=$	10
" " " 60,000	" " $=$	1

For class M watt-hour meters—

Numbers beginning with 15,000	denote $K_r =$	100
" " " 20,000	" " $=$	10
" " " 30,000	" " $=$	1

For class S watt-hour meters—

Numbers beginning with 10,000	denote $K_r =$	1
" " " 14,000	" " $=$	10

For class T watt-hour meters—

Numbers beginning with 8,000	denote $K_r =$	100
" " " 8,400	" " $=$	miscellaneous
" " " 8,500	" " $=$	10

In addition to this the ampere capacity and voltages are designated by allotting 1,000 numbers to each capacity as follows:

For class K watt-hour meters—

Numbers beginning with	55,000,	100 amp.,	220 v.,	denote K_r	= 10
" " "	56,000,	150 "	220 "	" "	= 10
" " "	57,000,	200 "	220 "	" "	= 10
" " "	60,000,	3 "	100 "	" "	= 1
" " "	61,000,	5 "	100 "	" "	= 1
" " "	66,000,	10 "	100 "	" "	= 1
" " "	70,000,	3 "	220 "	" "	= 1
" " "	76,000,	10 "	220 "	" "	= 1

By this system, a watt-hour meter once properly numbered can be checked as to ampere capacity, volts and register constant by comparison with the tables.

After meters are numbered, cleaned and tested, those meters which meet all test requirements are sealed and placed on the trucks, and then delivered to the stock room ready for issuance for service.

It is customary to store watt-hour meters on shelves, or racks, several tiers in height, providing sections for tested and untested meters, the various sizes and types being kept segregated.

From the tested stock the **watt-hour meters** are **delivered** to the installers, who then take them out in horse-drawn wagons, street cars, electric and gasoline automobiles, motor cycles or bicycles. All of these vehicles for transportation should be provided with special watt-hour meter compartments with cushions on the bottom, or some material which will protect the meters from being jarred in transportation.

A suggested arrangement would be to have a bed of excelsior, or cushion, on the bottom of the wagons, on which the watt-hour meters are placed. One company has made a shoulder-strap arrangement, with snaphooks on them, to fit over the shoulders of the men. This arrangement allows the men to carry four watt-hour meters, two in front and two behind, using street cars as a method of transportation. This allows the men free use of both hands to carry the necessary lamps.

An advantageous system of installing watt-hour meters is to have an automobile deliver the meters, lamps, etc., and have the installers follow up the delivery trucks. The following diagrams indicate graphically suggestive routine in the handling and maintenance of watt-hour meters (Figs. 242 and 243).

Watt-hour meters removed from service are placed on certain shelves, or racks, provided for that purpose. The meter numbers and register readings should be checked by a clerk. This considerably assists where the companies turn their dial hands back to zero before reinstalling.

The question of **service watt-hour meter location** should be carefully considered in the first stages of laying out the installation.

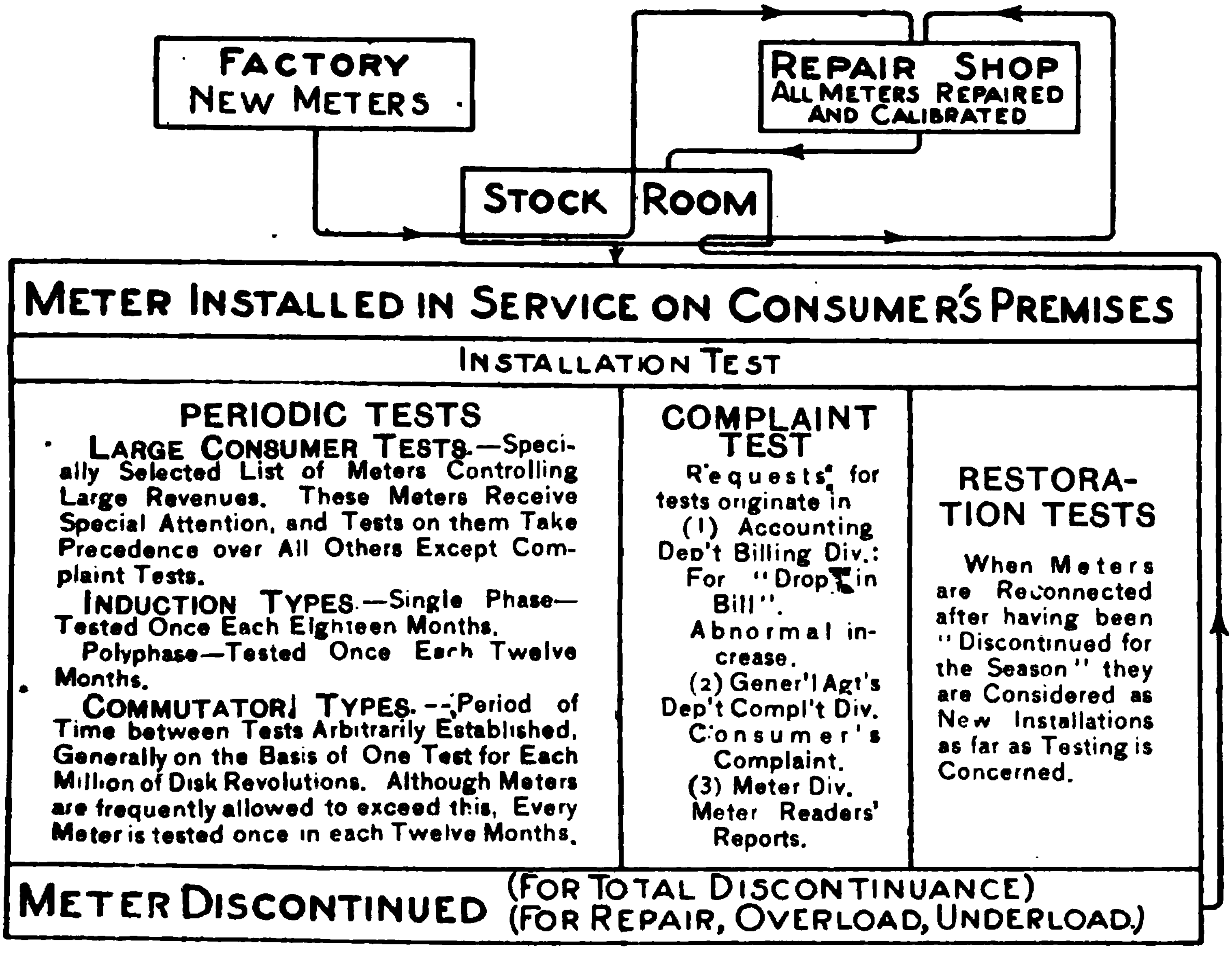


FIG. 242.—Suggestive Diagram of Routine of Handling Watt-hour Meters.

The continued accuracy of the meter is dependent to some extent on its location. As the meter registers the income of the company, and as the meter board is in many cases the distributing point where fuses and switches are located, it is, therefore, not only for the sake of accuracy, but for convenience in reading and testing and operation, to the interest of both the consumer and the company that a suitable location be provided.

In new buildings, especially in the case of large office buildings and apartment houses, special watt-hour meter closets of ample size

should be provided in the halls or the basement, from which separate circuits run to the different suites. The company should keep the architects and contractors informed as to the requirements, and the provisions for installing the meters must be such as to meet the

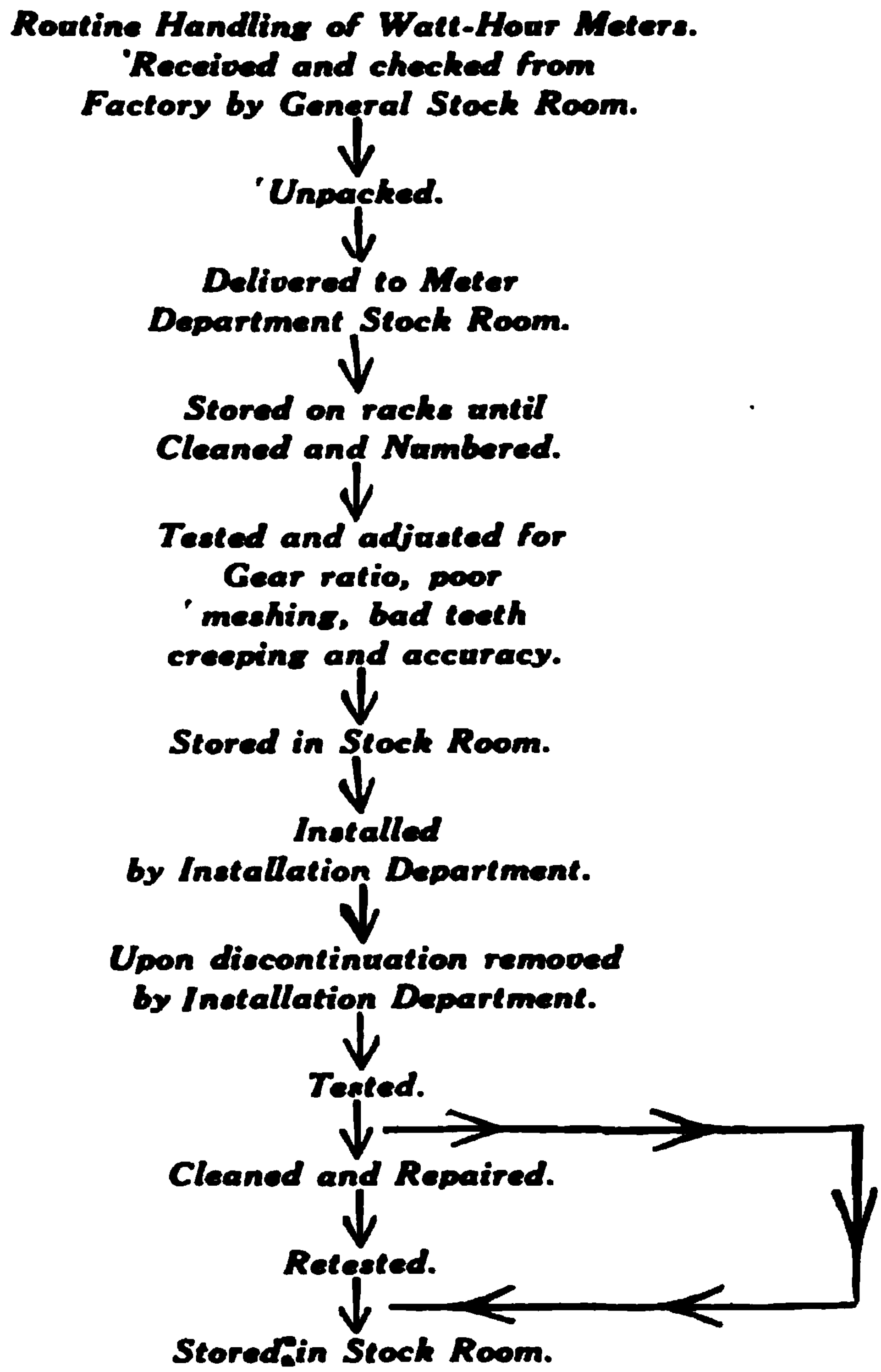


Fig. 243.

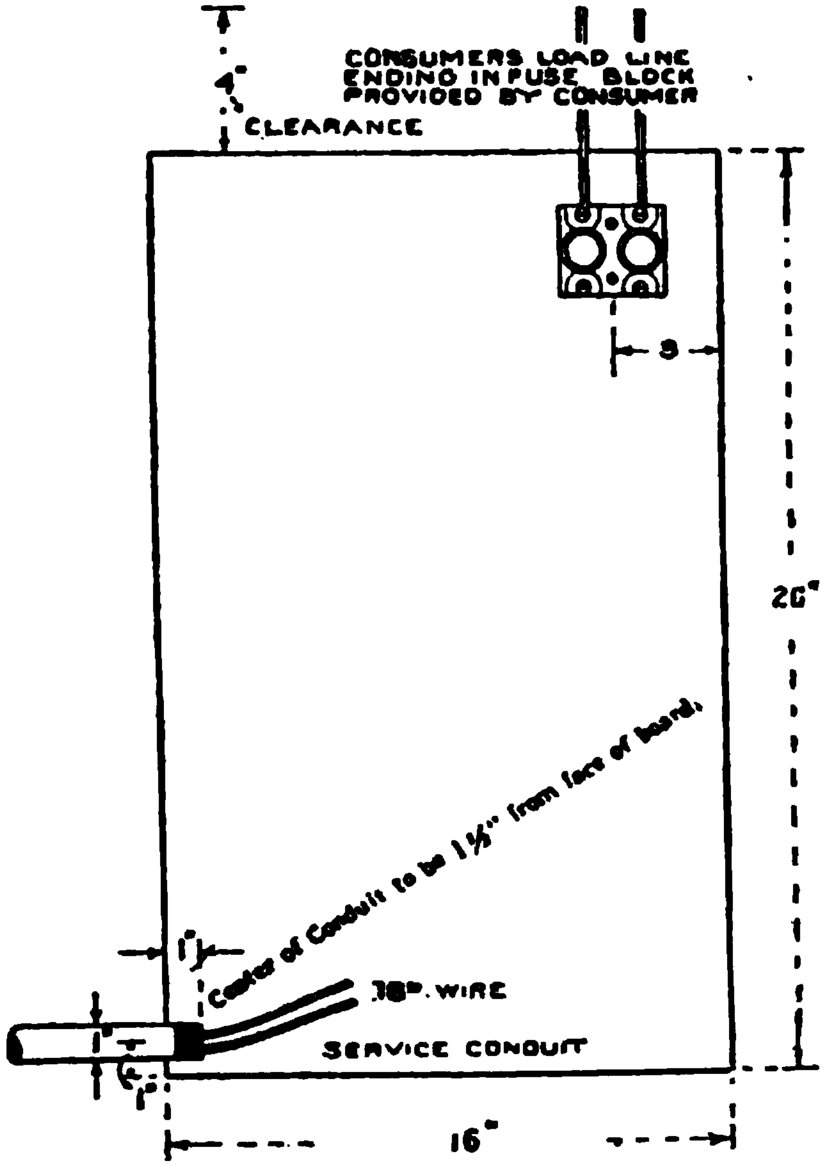
approval of the company's representative, especially in regard to facilities for testing. In old buildings it often occurs that an ideal location cannot be obtained, and a compromise must be made by choosing the location with the fewest undesirable features.

Watt-hour meters should be installed in the nearest suitable location to the point where the service enters the building.

PLACE METER BOARD HERE

READ CAREFULLY

The Buffalo General Electric Company will run the mains from the pole to a point ***20 ft.*** from the ground. **Consumer** must run from this point to his load with not less than No. 8 rubber covered wire, which must be enclosed in conduit with approved fittings ***up to the meter.*** ***All*** boxes between entrance of building and meter must be drilled for sealing. A **board** fastened ***securely*** to the wall must be provided for the meter This board to be of ⅞" soft pine with 2 coats of ***black*** paint. ***All dimensions of board and pipe ending*** must be as indicated in cut below. ***All*** space on meter board shown below, to be reserved for meter and service box. If space for additional fuses is required the board must be made larger to care for them.



The consumer's contractor should install board and service first, as the company will do no work on premises until such is done.

The Board of Fire Underwriters *require* that your wiring and fixtures be inspected *before* we give you current.

Standard meter board for 100 and 200 volts, D. C. or A. C., single phase, two wire, up to and including 50 amperes, or 220 volts, D. C. or A. C., single phase, three wire, up to and including 25 amperes capacity.

Any changes in the above must be approved by the Company's Inspector. When the above instructions have been complied with, phone the Meter Dep't of the Company (Frontier 3429 or Seneca 2830) for a final inspection.

BUFFALO GENERAL ELECTRIC CO.

FIG. 344.—Instructions to Contractors.

Meter boards are usually placed by the company, but when watt-hour meters are to be placed on switchboards, the consumer or contractor should do the necessary drilling, the proper template or drawing being furnished by the company upon request. The illustration (Fig. 244) represents a card which one company uses to indicate to contractor what location has been selected for the consumer's watt-hour meter. This company does not place the meter board, and complete instructions to contractor are given on the card. Some companies issue their instructions to contractors in book or pamphlet form.

The circuit should be enclosed in continuous iron conduit from the service to the meter. The requirements of the meter should, therefore, be considered in locating the service, and the inspector who determines the location of the service should either have sufficient knowledge of the meter to know what to avoid or should work under rules which are adequate to insure the proper results. The requirements of a suitable meter location are given in the following clauses.

The watt-hour meter should be accessible with a minimum of annoyance to the tenants; should be so located that it may be easily read and should have sufficient space around it so that the tester has no difficulty in arranging and using his apparatus, or in inspecting and adjusting the meter.

The watt-hour meter should be installed not more than 7 feet from the floor, on a stable support, in a clean, dry, safe place, free from vibration and magnetic disturbances. Among undesirable locations may be mentioned the following: In bedroom closets, bath or toilet rooms, attics, coal bins, elevator or ventilating shafts; near stoves or radiators, steam or gas piping, electric machinery; over doors, or on wooden partitions.

The location selected should be free from moisture, and in this connection the possibility of future moisture resulting from "sweating" should be considered, i. e., a watt-hour meter should never be placed under a waterpipe, from which, as a result of "sweating," water may drip. When a damp location is unavoidable, a moisture-proof box should be provided to contain the meter.

Watt-hour meters should be so located that they will not be exposed to mechanical injury. This requirement makes it undesirable to place a meter at a less distance than five or six feet from the floor. If it should be necessary to locate the meter near the floor, or in a position where it would be exposed to mechanical injury, a good stout box must be provided to contain the meter, and thus horoughly protect it from any possible damage.

The location of the watt-hour meters and the service cut-outs upon the premises of any person other than the one whose installation is controlled by them is to be avoided unless they are accessible at all times.

In cases where it is necessary to recess a meter in the wall, a meter cabinet must be provided, the walls and door of which must be made of some fireproof material. If metal is used, it should not be iron or steel and must be covered with some form of insulation so as to prevent the possibility of a short circuit when connecting, disconnecting or testing meters.

When a number of watt-hour meters are installed together, the distance between centers should not be less than 15 inches.

The following remarks on wiring, deal only with those aspects of **wiring necessary to satisfactory metering** and, therefore, no regulations as to allowable drop, balancing of three-wire circuits, grounding, et cetera, are included, nor do the regulations of this section duplicate, or conflict with, the Electrical Code of the National Board of Fire Underwriters.

The company has the right to inspect all circuits and apparatus at any time to insure that they are properly metered.

Each meter should be protected by its own sealed cut-out, placed between the meter and the point where the service enters the building.

No meter should be so connected as to include the registration of another meter, except for purposes of special investigation or where required by special conditions.

Where several meters are grouped together, the circuit in which each one is connected should be plainly indicated, and all circuits should be carefully traced to insure that there is no error in the wiring whereby one consumer obtains current through another consumer's meter. This is especially important where the wiring is concealed, in which case the service and load wires should be tagged.

Open wiring, where used, should be arranged with a view to minimizing the likelihood of incorrect or improper connections. The wiring around the meter should be arranged neatly, without unnecessary crossing, and in such a manner as to minimize the liability to confusion between the different circuits.

Both sides of a two-wire circuit should, where practicable, be carried through the meter. When this is done, the meter should be tested with the return bar in circuit, unless comparative tests with and without the return circuit show the given type and capacity of meter to be unaffected.

In two- and three-wire circuits, where a separate potential tap is used, precaution should be taken to prevent its becoming disconnected. The connecting wire should be as short as possible, should be accessible for inspection and should be soldered to the return or neutral circuit. Where several branch circuits are supplied through the same meter, the potential tap should be carried back to the main line. Otherwise, it may become disconnected by the opening of the fuse in one of the branch circuits.

In wiring three-wire watt-hour meters care should be taken that both the current coils are connected in the outside wires and that they are not connected in opposition.

In wiring polyphase watt-hour meters, especially when used with voltage and current transformers, great care is necessary to obtain the right connections. The meters should be wired in exact accordance with the manufacturer's diagram, and in addition the connections should be tested out to insure that the meter operates correctly (Chapter VIII).

The wiremen should leave a free end at least 18 inches long on each circuit to give ample wire for connection to the watt-hour meter.

Where no watt-hour meter terminal box is used, the conduit for the service wiring and the conduit or molding for the house wiring must terminate at a sufficient distance (6 inches or more) from the meter to permit easily changing the connections for testing purposes.

Where watt-hour meters are installed in closets or compartments, the conduit or molding should terminate in plain view within the compartment. In a three-wire circuit the neutral, and in a two-wire circuit the grounded, side of the circuit should pass through the compartment.

In recent years much more attention has been given to the **installation of watt-hour meters** than formerly, in order to lessen the cost of maintenance and the posibility of tampering.

When open wiring is used, it is preferable to mount the watt-hour meter and the service cut-out on a suitable meter board of standard size, which is securely fastened to the wall. On bricks, concrete, terra cotta or metal walls the boards must be set out from the wall, leaving an air space of at least ⅞ of an inch back of the board. While the method of installing meters with open wiring, unprotected cut-outs and switches on both the service and the house sides of the meter is still practiced, yet it is no longer considered safe or satisfactory by many companies, especially in the larger cities.

The best modern practice requires that the design of the installation should be compact and should be standard; or, rather, the several designs to meet different conditions should be standard, in order that all watt-hour meters can be erected in substantially the same manner. The design of the installation should also be of such a character that the several parts are interchangeable. In the design should also be combined durability, flexibility, as low first cost as possible, and a minimum of opportunities for tampering, and similar features. All of the wiring and connections between the service and watt-hour meters should be enclosed in metal or its equivalent, and all switches and cut-outs between the service and meters should be protected.

It is good practice in many instances to employ **meter installation devices** which, together with the continuous conduit and the sealed service cut-outs enclose and seal all the wiring around the watt-hour meter. Complete protection is thus provided for all unmetered parts of the circuit. Detailed descriptions of such devices are given in Chapter XIV.

Generally a standard form of box is employed with metallic trim for fitting it to the various types of meter. In some cases, the service cut-out is incorporated in the device.

By a proper design of the installation device, the ease and accuracy of testing may be increased.

The material used in connection with the watt-hour meter installation should be of the best quality obtainable, as the service and meters are frequently located in cellars where dampness exists, and worse conditions generally than in other parts of the building. The use of wood should be eliminated so far as possible. The work should be performed by skilled mechanics, possessed of good judgment and a fair knowledge of the meter.

The arrangement should be such that the greatest stability and safety is obtained, in order to insure a continued and uninterrupted service and to render unquestionable any possibility of fire occurring due to any defects in this part of the electrical equipment; as, owing to the location, it is generally subjected to rougher usage than other parts of the installation, and is more often surrounded by inflammable material than similar apparatus in other parts of the building.

In the case of induction coils, wireless telegraph apparatus, high potential testing transformers, et cetera, where the high voltage, or high frequencies produced are likely to injure the watt-hour meter or to interfere with accurate registration, the consumer should install an approved device capable of protecting the company's apparatus fron

the injurious disturbances. One remedy is to place a one to one ratio load transformer between the meter and the consumer's circuit and another is an arrangement of condensers so connected as to dissipate the capacity charge which accumulates on this type of circuit. The form of apparatus required will differ under different conditions, and should be designed in consultation with, and with the approval of, the company's engineers.

The following extracts, concerning the service watt-hour meters, from rules issued by one of the larger companies to architects and wiring contractors, as well as to its own employees, indicates the company's practice in this respect.

1. The watt-hour meter and service cut-out and cut-out box will be furnished and installed by the company, and will always remain the property of the company.

2. The final connections from the service to the service cut-out and to the watt-hour meter will be made by the company, and the service fuses will be placed by the company. Contractors and others are requested to warn their employees against any infraction of this rule.

3. The connections from the service to the service cut-out and to the watt-hour meter must not be altered, or the position of either be changed, except by a representative of the company. Consumers and contractors must notify the company in the event of any alterations being required.

4. Unless the particular conditions of the case do not permit it, and special arrangements are made with the company, all watt-hour meters will be installed in cellars, except in such cases as the following:

(a) Buildings which were wired prior to the issuance of these rules and have watt-hour meter loops left in other locations.

(b) Buildings which have no cellars, in which case the watt-hour meters will be installed on the first floor.

(c) Buildings in which the various floors are rented separately, in which case the watt-hour meter may be installed on the particular floor to which the current is supplied.

(d) Office buildings and apartment houses. If separate watt-hour meters are required for each office or suite, the meters for each floor may be installed in the hallway of that floor. The watt-hour meter loops in such cases must be brought out in one location in the hallway for all the offices or rooms on the particular floor.

5. Under no circumstances will watt-hour meters be installed in bathrooms, bedrooms, sitting rooms, bulk windows, over doors, or in locations likely to cause the visits of the meter reader or tester to be of the least annoyance or trouble to the consumer.

Watt-hour meters will also not be erected on partitions or other supports liable to excessive vibration, or in locations subjected to extremes of temperature.

The main fuses and switches are usually located at the watt-hour meter board, and it is to the interest of the consumer, as well as of the company, that the apparatus should be in a fairly convenient location and accessible at all times.

6. Watt-hour meters will be erected at, or as near as possible to, the point of entrance of the service, and at a height of approximately five feet from the floor.

7. The house wiring must be terminated in a cut-out and switch, erected one above the other, the cut-out being placed between the switch and the watt-hour meter.

8. The service cut-out installed by the company will be enclosed in an iron box and will be sealed.

9. Watt-hour meters will not be erected on the switchboards, or panel boards, of consumers, unless such boards are in close proximity to the service cut-out box and the board is so arranged that the meter wiring and connections may be on the front of the board. (See Rule 12.) Unprotected connections on the service side of the meter will not be permitted.

10. All wiring from the service end to the watt-hour meter must be run in continuous conduit.

11. Where closets are erected for watt-hour meters, the service conduit must terminate inside the closet in plain view and in such a position that the service cut-out box may be placed on the end of the conduit.

Watt-hour meter closets must be of sufficient dimensions to allow of the easy removal of the watt-hour meter cover, and must permit a clearance of at least six inches below and on each side of the watt-hour meter.

12. The standard types of watt-hour meters used by the company are front connected, and no back connected meters will be installed.

13. The dimensions of watt-hour meters used on continuous current circuits are shown on pages .. and .., and on alternating current circuits on pages .. and ...

14. The general types of meter boards erected by the company

for continuous current circuits are shown on pages .. and .., and for alternating current circuits on pages .. and ...

15. The service cut-out boxes and watt-hour meters of the company are sealed. The breaking of these seals by unauthorized persons, or the tampering with the watt-hour meters, cut-outs, wire or any property of the company is prohibited by law, and will not be permitted by the company. Attention is called to the Act of Legislature bearing on this matter.

Similar rules issued by another company follow:

"In selecting a location for the company's watt-hour meters, the following points should be borne in mind. For commercial consumers, such as stores, offices and loft buildings, watt-hour meters should, when possible, be located at the point of service entrance.

"In apartment houses it is recommended that meters be placed in the basement, so that the consumers will not be inconvenienced by the company's employees when it is necessary to inspect, read or test.

"The location selected should be free from moisture, and in this connection the possibility of future moisture resulting from "sweating" should be considered, i. e., a meter should never be placed under a waterpipe, from which, as a result of "sweating," water may drip. When a damp location is unavoidable, a moisture-proof box must be provided by the consumer to contain the meter.

"The location selected should be free from vibration, and where possible the watt-hour meter should be located upon a substantial wall and not upon a wooden partition.

"Watt-hour meters should be so located that they will be easily accessible for testing and indexing. This restricts the location of the meter to between six and eight feet from the floor, and prevents the selection of a bathroom, bedroom closet, or in any other room which is usually kept locked, and prohibits the installation of a watt-hour meter in an elevator shaft.

"Watt-hour meters should be so located that they will not be exposed to mechanical injury. This requirement makes it undesirable to place a meter at less distance than six feet from the floor. If it should be necessary to locate the watt-hour meter near the floor, or in a position where it would be exposed to mechanical injury, a good stout box must be provided by the consumer to contain the meter, and thus thoroughly protect it from any possible damage.

"The location of a watt-hour meter and the cut-out controlling

the same upon the premises of any person other than the one whose installation is to be controlled by the meter is to be avoided.

"In cases where it is necessary to recess a meter in the wall, the contractor is to provide a cabinet, the walls and door of which must be made of some fireproof material. If metal is used, it must be covered with some form of insulation so as to prevent the possibility of a short circuit when connecting, disconnecting or testing meters.

"The minimum inside dimensions of the cabinet to contain a single watt-hour meter are to be 16 inches wide by 22 inches high, and with a minimum depth of 12 inches.

"When two or more watt-hour meters are to be located in the same box, the distance between the meter centers must not be less than 15 inches.

"When it is necessary to place a watt-hour meter in a restaurant kitchen, or similar place, a suitable cabinet or closet 16 inches wide, 22 inches high and 12 inches deep, fitted with a hinged door and a secure latch must be provided by the consumer. When it is necessary to place a watt-hour meter on a wall where it may be surrounded by shelving, a space at least 16 inches wide and 22 inches high must be provided.

"Watt-hour meter boards will be placed by the company, but when meters are to be placed on switchboards, the consumer, or contractor, must do the necessary drilling, the proper template or drawing being furnished by the company upon request.

"Switchboards should be subdivided so that they will not require a meter larger than 300 amperes for each section and arranged so that the service wires or connections can be protected.

"Watt-hour meter distributing panels, or those having meter outlets, will not be approved.

"Where switchboards are to be used, the question of subdivision and metering should be taken up in advance, and it is recommended that the installation and inspection department be consulted before beginning work, so as to avoid any confusion and misunderstanding.

"In order to show more clearly the application of the above rules, the following cuts of typical watt-hour meter installations are shown. These cuts indicate the arrangement of watt-hour meter connections and the cut-outs which will be furnished by the company." (See Chapter XIV.)

The above rules are merely an arrangement of the principles set forth earlier in the discussion and apply to the types and sizes of watt-hour meters used by a specific company, but they are recited here for the convenience of any company about to formulate such rule

CHAPTER VII

WATT-HOUR METER TESTING

CHAPTER VII

Watt-Hour Meter Testing

'he **efforts** of the world in all matters of physical measurement **toward absolute accuracy.** It is probable that the question of ;asurement was among the earliest conceptions of the human mind. l civilized nations seem to have appreciated, early in their hisry, the confusion incident to the absence of official standards of ngth, weight, and so forth; and means were taken to procure standrds which, after official sanction, were deposited in temples and requently placed in the custody of the priesthood.

From these remote periods to the present time a persistent effort has been made to standardize all systems of measurement and improve the accuracy of the working standards.

This tendency toward accuracy of measurement is seen in all walks of life, as evidenced, for instance, in the checking of the capacity of the bottles used for distributing milk, and the periodic verification of the accuracy of the scales used by grocers and other tradesmen.

To-day no excuse exists for any tradesman using scales of whose accuracy he has the slightest doubt. It is his duty, both to himself and to his customers, to insure the accuracy of his weights. Honesty of intention requires that he shall do more than merely believe that his scales are correct; it is his unquestionable duty to his customers to know that they are correct.

So with the manager of an electric lighting company; he must not merely believe that his meters are accurate, but he must periodically test them to insure that they are correct.

The electricity meter operates under more varied and exacting conditions than almost any other piece of apparatus. It is frequently subjected to vibration, moisture and extremes of temperature; it must register accurately on varying voltages and various wave forms; it must operate for many months without any supervision or attention whatever; and, in spite of all these conditions, it is expected to register with accuracy from a few per cent of its rated capacity to a 50 per cent overload (Fig. 245).

As a meter is a type of machine, its natural tendency is to run slow; but occasionally, through accident, a meter may run fast. When a meter runs fast the consumer is paying a higher rate per kilowatt-hour than his contract calls for. He is being discriminated against. The periodic testing of meters is therefore a necessity and is an indication of the honesty of intention of the manager toward the customers of his company.

FIG. 245.—Typical Watt-hour Meter Accuracy Curves. on Varying Load Expressed in per cent. of Watt-hour Meter Capacity; on Varying Potential Expressed in Volts, and on Varying Frequency Expressed in Cycles.

Furthermore, the manager has the interests of his stock-holders always in mind; and as meters when in error are more apt to run slow than fast, the testing and calibrating of meters is indicative of his interest in the welfare of the stock-holders, for it follows that the maintenance of the accuracy of meters brings into the treasury of the company revenue that otherwise would escape.

Every manager is aware that the cost of electricity at the bus-bar is less than its cost at the consumer's premises; for, while only the generating expenses enter into the former, the latter is burdened

with the additional expenses and losses of distribution. At an equal profit, therefore, electricity can be sold at a lower rate per kilowatt-hour at the bus than at the consumers' premises; and the greater the distribution expenses become, the higher must be the rate to the consumer. When meters are not tested a large proportion of them run slow, thus increasing the cost of distribution. Under these conditions, a higher rate must be maintained; and the consumer whose meter is accurate is virtually paying for a part of the electricty used by the consumer whose meter is slow. This is manifestly unjust. It is, therefore, only by maintaining the accuracy of his meters that the manager is enabled to arrive at an equalization of the charges and fix just rates for all his consumers.

The manager, as a rule, has a lively appreciation of the necessity of economizing on his coal. He will frequently recommend the purchase of more expensive machinery and employ a higher grade of labor, if by so doing he can demonstrate that he is making a saving in the cost of his coal. If the manager will take the trouble to investigate he will find that a 1 per cent increase in the revenue, secured by maintaining the accuracy of his meters, is equal to several per cent of the cost of his coal; at times even as high as 10 per cent or more.

It is found that, while the ratio of meter capacity to connected load varies on different systems, yet, considered as a whole, it is not far from 1 to 1; that is, 1 kilowatt of meter capacity is installed for each kilowatt capacity of connected load. It is but seldom that the peak load exceeds from 30 to 60 per cent of the connected load and the generators seldom exceed 70 per cent of the connected load. It would appear from this that, on the average, the smaller companies have installed about 1.4 kilowatt of meter capacity for each kilowatt of generator capacity.

Assuming the cost of generators for smaller plants as averaging $12 per kilowatt and the cost of meters as $8 per kilowatt, it will be seen that the cost of meters is not far from the cost of generators. No manager would, for a moment, consider that his generators would continue to operate without constant attention; and, considering the capital invested, he should appreciate the necessity of giving proper attention to his meters, more especially when he remembers that this attention may effect a greater saving than an equal outlay on the generating part of his apparatus.

Some one has spoken of the meter as the cash register of the company. No customer would be willing to accept and pay for goods without knowing that both the quantity and the price were

correct, and no business man would expect a customer to do so. Therefore, no manager of an electric lighting company should expect his consumers to pay, without protest, their bills for electricity, when they know that the manager is making no conscientious effort to determine the quantity of electricity delivered.

It seems a wofully short-sighted policy to try to save on the generation and distribution of electricity from the coal pile to the meter and then neglect the meter, when it is considered that the losses at the meter may far exceed the saving secured all along the line. The old saying that "it is folly to save at the spigot and waste at the bung" seems appropriate.

Increased accuracy, more complete and systematic routine, more stringent requirements by State Commissions and consumers, and cheaper, simpler, smaller and more convenient types of instruments, exemplify the modern, up-to-date, consumer's watt-hour meter practice.

While **modern electricity meters are very reliable,** it would not be safe to assume that they register correctly year after year without some attention. It will therefore be only just to the consumer, as well as to the producer of electrical energy, if electricity meters be periodically and systematically compared with a known standard, and when found in error be either adjusted to register correctly, or, if found impracticable to recalibrate, replaced by a correct meter.

The object of testing and adjusting meters carefully and at regular intervals is twofold.

One object is the maintenance of the meter in a condition where its accuracy will be the greatest. This, as stated in the Code for Electricity Meters, is not accomplished by allowing the cause of inaccuracy to continue and compensating for the same by the adjustment of the meter, but by removing the cause where possible, or otherwise by removing the meter.

The second object of systematic meter testing is to so maintain the meters, similarly to all other equipment used in furnishing the service, that they shall have as long a useful life as good economy of operation allows.

The absolute knowledge that meters are correct, places one on a better basis with consumers, and the good will thus gained is on a par with the best advertising.

Considerable time and energy are devoted to the consideration of the condition and operating efficiency of the boilers, engines, generators, switchboards, and various labor-saving and economical devices for production of electricity, while the matter of transporta-

tion and sale of current is sometimes not given the attention its importance demands. Contemplate what the criticism would be of a manufacturing concern that devoted every facility to the cheap and efficient production of its wares and paid no attention to the transportation, delivery and billing of the manufactured article.

Past **experience has proven that electricity meters should be systematically tested,** if a high degree of accuracy is to be maintained. Results of many tests gathered up to the present date show a greater tendency of meters to run slow than to run fast, therefore a considerable amount of profitable work can be placed upon them.

Public service commissions have now been created to assume control of public utilities in many places, and where this has been done, there are limits fixed relative to the required accuracy of meters, and periodic tests at specified intervals are requested. In some places these commissions will, or do, make tests on consumers' premises and, when they do, it will, to say the least, be found gratifying to the company if its meters are reported correct by the commission. The indications are that the number of these public service commissions will be increased, and when companies come under this control, they will naturally find it greatly to their advantage, if their meters are found in good condition.

Accuracy can only **be maintained** by frequent and intelligent inspection and testing.

Periodic Tests should be made as often as is necessary to insure continued reliability and commercial accuracy of the entire meter system. Due to accidental causes and conditions in the consumer's premises which are beyond the control of the company, errors will always be found in a few cases, but in a well-maintained system the proportion of the meters found in error will be small.

The period should vary according to the conditions of the case. The accuracy of meters of various types operating in different locations and under different conditions of use will have varying degrees of permanency. This factor should therefore be taken into account in determining the frequency of testing of individual meters.

Meters controlling a very large amount of revenue may be tested as often as once a month, while the ordinary run of meters should be tested at least once a year, once in eighteen months, or once in two years, the period varying with different companies, different types and different civic requirements.

For testing purposes meters should be divided, in general, into two classes according to type; commutator type meters and induction meters. Induction meters having light moving elements and no com-

mutators will give good results over long periods of time. It is generally acknowledged that the period between tests can be longer in the case of induction meters than in the case of commutator type meters. The tendency in the case of induction meters, since the production of modern types, is to extend the period, whereas the maximum period of about one year is generally accepted for commutator type meters.

Commutator-type meters, having comparatively heavy moving elements with consequent rapid increase in friction due to wear on the jewel and bearings, and a commutator also increasing in friction with age, must have frequent and expert attention to insure their accuracy under all conditions.

The following is a suggestive **schedule of routine periodic tests** indicative of modern practice:

Modern Type Alternating Current Induction Meters

All single-phase induction meters, two-wire or three-wire, up to and including 25 amperes rated capacity, to be tested once in 24 months.

All single-phase induction meters, two-wire or three-wire, over 25 amperes rated capacity, to be tested at least once in 12 months.

All polyphase induction meters up to and including 150 amperes, to be tested at least once in 12 months.

All polyphase induction meters over 150 amperes rated capacity, to be tested at least once in 6 months.

Continuous Current Commutator Type Meters

All continuous current commutator type meters, two- or three-wire, 110 or 220 volts, up to and including 25 amperes rated capacity, to be tested at least once in 12 to 15 months.

All continuous current commutator type meters, two- or three-wire, 110 to 220 volts, 50 to 150 amperes rated capacity, to be tested at least once in 9 to 12 months.

All continuous current commutator type meters rated at 150 to 600 amperes, to be tested at least once in 6 months.

All continuous current commutator type meters rated in excess of 600 amperes, to be tested every 3 months.

Commutator type meters of 300 volts and over should be tested at least once every six months.

In commutator meters having heavy-moving elements and sapphire jewels, the number of revolutions of the moving element between

tests should not, ordinarily, exceed 1,000,000. Meters having lighter-moving elements and particularly meters having diamond jewels may be allowed to exceed this limit.

According to this rule, meters which operate at a heavy load during a considerable proportion of the time, resulting in a larger number of revolutions of the moving element between tests, should be assigned to more frequent tests to compensate for the effect of wear.

The results of the meter tests should be followed carefully, and where a given meter shows continued liability to error, the cause should be investigated and removed, if practicable. Otherwise, the frequency of testing should be increased with a view to keeping the meter within commercial limits. Often it is found necessary to change meters from one class to a class which is tested more frequently on account of a long hour load or other conditions. Whenever it is found that a meter tested according to schedule is continually falling below the limits, it should be changed to a class which is tested more frequently.

Many companies choose, of their own volition, to increase the frequency of the testing of meters controlling a large amount of revenue on account of the larger monetary effect of a given percentage error. Monthly tests, based upon the above principle, have been found to be none too frequent in some cases.

When it appears that the object of the applicant company in making such application is to obtain a higher degree of meter accuracy rather than to reduce the amount of meter-testing work required, civic commissions are inclined to grant extensions of the allowable time intervals between periodic tests, in conformity with schedules of best commercial meter practice.

Probably the most important problem for the laboratory division to solve is the proper classification of its meters into test groups, so that each meter will be tested before it shall have reached a point on the error curve outside of certain predetermined limits.

Since it is essential to the selection of proper types and to the maintenance of the accuracy of electricity meters in service that thorough and systematic tests be carried out and that the meters be readjusted from time to time to eliminate the effect of the sources of error enumerated, meter tests have been divided into two general classes: **Acceptance Tests** and **System Tests**, and into several subclasses.

In addition to the various formal tests outlined in this Handbook, it is advisable for each company to make special tests to determine

the properties and behavior of the meter used under its special local conditions. The character of such tests should be dictated by the requirements of the individual case.

1.—**The Acceptance Test.**—This is a test made on a particular type of meter to ascertain, if it will register, with commercial accuracy, the electrical energy which passes through it. (See Code for Electricity Meters, Sec. IV.)

System Tests should be conducted according to the approved methods specified in this Handbook, using standards complying with the requirements also given herein.

2.—**System Tests** may be classified as follows:

(a) **The Laboratory Test,** made in the laboratory of the meter department or in the meter shop of the company, prior to installation.

(b) **The Installation Test,** made within a limited period of time after installation.

(c) **Periodic Tests,** made at regular intervals on the consumer's premises.

(d) **Complaint Tests,** made upon complaint of the consumer.

(e) **Inquiry Tests,** originating with the company, and made for the purpose of investigating the cause of apparently abnormal registration of individual meters.

(f) **Repair Tests,** made after meters have been repaired in service.

(g) **Check Tests,** made for the purpose of verifying previous tests.

(h) **Referee Tests,** made in the presence of a representative of a disinterested authority.

(i) **Special Tests,** covering cases other than those included in the above classes.

(j) **Inspections,** including merely an examination of the meter and the conditions surrounding it, for causes of error, but including no adjustment or precise determination of its accuracy.

Meters may be tested by any of the methods outlined in Chapter VIII. The instruments and apparatus to be utilized in making these tests are described in Chapters V and IX. The proper connections for testing all types of meters are shown in Figs. 260 to 301.

New meters should be unpacked with care and given a general examination for damage in transportation, marked according to the company's method of identification and entered in the stock records.

The Laboratory Test:

The Laboratory Test should then be made as follows:

In the case of new meters, readings for accuracy should be taken

as a check on the manufacturer and to disclose injuries received during transportation.

The meters should be carefully examined to detect defects and errors in manufacture and to insure that all mechanical parts are in proper adjustment. The gear ratio should be determined by actual count and used in interchecking the register and test constants. Where not already so marked, the watt-hour or watt-second constants should be marked on the meter. The serial number of the meter should be marked on the back of the register to enable easy detection of interchanged registers.

Unless already within this limit, the meter should be adjusted correct, within 1 per cent at light load and full load, as follows:

Commutator type meters:

Light load = 10 per cent of rated capacity.
Full load = 50 to 100 per cent of rated capacity.

Induction meters: On non-inductive load.

Light load = 5 or 10 per cent of rated capacity.
Full load = 50 to 100 per cent of rated capacity.

Meters to be used on alternating current circuits liable to inductive loads should also be tested at 100 per cent of rated current on inductive load (lagging), and, if necessary, readjusted. If tested at 70 per cent power-factor, the meter should be adjusted within one per cent of the accuracy at unity power-factor. If tested at 50 per cent power-factor, the meter should be adjusted within 2 per cent of the accuracy at unity power-factor.

In making the final adjustment, the tester should note that each adjusting device is in good condition and that it has sufficient range in either direction to admit of adjustment on the consumer's premises under service conditions.

Meters returned from service should be treated substantially as are new meters, and, in addition, each one should be thoroughly overhauled and put into a state of repair equal to that of a new meter.

If the gear ratio has been previously determined and the serial number marked on the register, so that its identification is certain, a redetermination of the gear ratio is unnecessary.

Instructions for manipulating the various parts of the more important types of meters will be given in Chapter XVI.

In the case of meters returned from service it is desirable that register readings and readings of accuracy "as found" be taken

before any changes are made in the meter. These readings, if taken, should be recorded for use in settling possible complaints involving the time between the last test of the meter and its removal. Many points mentioned in connection with tests on consumer's premises may be applied to laboratory work.

Tests of meters on the consumer's premises have the following objects:

The determination of the accuracy and the register reading of the meter "as found."

The readjustment and recalibration of the meter.

The verification of the accuracy "as left."

Attention must also be given to such conditions as are likely to affect the accuracy of the meter, or its proper registration, or to render it inoperative at any time between the given test and the next periodic test.

It is advisable in all cases to lay down **definite rules** which are to be observed in carrying out tests on the consumer's premises. While modifications may be necessary to satisfy local conditions, the essential principles laid down in the following set of rules should be adhered to in all cases:

RULES OF PROCEDURE IN TESTING ON THE CONSUMER'S PREMISES

RULE I

Before attempting to enter the premises or to work on the meter, the tester should always make known his presence to the consumer, or his representative; identify himself as the representative of the company, and show evidence of his authority to test the meter by exhibiting his badge or identification card.

RULE II

The tester should on reaching the meter, verify its number to insure that it is the one on which the test is ordered.

RULE III

An inspection of the general conditions around the meter should then be made. Where the location is dirty, dirt, cobwebs, etc., which are likely to fall into the meter, should be removed. Conditions of temperature, stray fields, vibration, etc., which are likely to affect the accuracy of the meter, should, however, be disturbed as

little as possible prior to obtaining the "as found" readings, in order that such readings may represent as nearly as possible the accuracy of the meter in service prior to the test.

The condition of the seals on the meter should be examined and the wiring leading to the meter should be inspected to detect improper or fraudulent connections. When tampering is suspected, or detected, it is very important that no alterations be made in the meter or any of its connections, but that the entire installation be left entirely untouched. The case should be at once reported to the proper official of the company, the report including such observations of the circumstances as can be made, without disturbing in any way the conditions and without arousing the suspicions of the consumer.

Rule IV

Before opening the meter, the reading of the register should be taken, recorded and checked.

Rule V

The tester should note whether the meter is creeping, if possible, before removing the cover. If the meter is found creeping, the rate of creep, in terms of the time required for one revolution, should be determined and entered in the test record. In testing for creep, the house wires should be disconnected from the meter.

The cover should be removed carefully, the consumer's load shunted when necessary, and the standards connected in circuit. A determination of the load required to start the meter may advantageously be made at this point.

Rule VI

Readings of accuracy "as found" should be taken at the following loads:

Light load, equal to 10 per cent of the meter capacity in commutator type meters, and 5 or 10 per cent of the meter capacity in induction meters.

Full load, equal to 50 to 100 per cent of the meter capacity.

Normal load, when required.

These readings should be taken in accordance with the rules laid down in Chapter VIII.

Rule VII

In meters on grounded systems, a test should be made to determine that the current coil of the meter is in the ungrounded side of the circuit. This test is made by connecting a voltmeter, or incandescent lamp, from either terminal of the current coil to a grounded object, such as an active water pipe. If the coil is in the grounded side, no voltage between the coil and ground will be obtained, and the condition should be corrected, or reported for correction.

Rule VIII

The meter should then be thoroughly overhauled and adjusted in accordance with the proper directions for the given type.

Rule IX

The tester should see that the meter is properly installed, is level, is securely supported, etc. External sources of error, such as vibration, heat, moisture, chemical fumes, abnormal amounts of dust, etc., and also the causes of any abnormal condition found within the meter should be investigated and eliminated or reported for correction.

Rule X

The meter should then be recalibrated with the same loads as are given above for the "as found" test. Final readings should be taken at each load.

Rule XI

Creeping meters should, in all cases, be corrected. If the creep cannot be removed by the use of the adjustments of the meter, or if the meter is subject to intermittent vibration, the effect of which at other times than that of the test cannot be determined, a small iron wire known as a "clip" should be placed on the disk and so adjusted that as it passes the brake magnets, it will be attracted by a force just sufficient to prevent rotation at no load.

After installing the clip, final readings should be taken of starting current and accuracy at light load and the accuracy readjusted, if necessary.

Rule XII

The meter should then be reconnected, closed and sealed. The final reading of the register should in all cases be carefully checked and recorded, after the meter is sealed.

Rule XIII

Before leaving the meter, the tester should see that it records, and that the consumer's circuit is complete.

Rule XIV

All entries in the test record must be made at the time when the corresponding work is done.

The Installation Test:

The character of **the Installation Test** is similar to that of other service tests, special attention, however, being paid to the local conditions surrounding the installation.

The period between the installation of the meter and the installation test should in general be long enough to allow the meter, and the conditions around it, to reach a fairly permanent state, but not long enough to permit a large registration. In practice, this period does not exceed thirty days.

In some cases an installation inspection is made immediately after installation, with a view to determining that the meter is in good operating condition, properly connected, and that the location is such as to insure proper metering conditions. Where such an inspection is made, the period between the installation of the meter and the installation test may be longer than otherwise.

In the case of induction meters the installation tests and installation inspection may be combined, or in some cases the installation test may be omitted when a thorough installation inspection has been made. Commutator type meters should invariably receive the installation test.

The installation test should ordinarily not be made until after the consumer's installation is complete.

A longer interval should be allowed in the case of commutator type meters than in the case of induction meters, to permit aging of th

commutator. Where the installation inspection is not sufficient to insure fairly accurate operation of the meter, it may be necessary to shorten the interval to a few days, even on continuous current meters. This practice is permissible only when local conditions are such that possible errors in registration, in the interval of time between the installation and the installation test, are of more importance than the effects of aging.

Where the meters are scattered over a large territory, the period will be governed to a limited extent by the necessity of testing various meters in the same locality on the same day.

Complaint Tests:

Meters should be **tested on complaint** of the consumer:

(a) Whenever, after the elimination of other causes of dissatisfaction, it appears possible that the meter is at fault.

(b) Whenever, in the judgment of the company, a test is desirable.

The consumer, if he desires it, should be allowed to have a representative present to check the test at all points.

The loads to be used in testing should be chosen with a view to obtaining the best measure of the accuracy with which the meter registers the energy consumed. When the normal service loads cannot be determined, the method of testing at three loads may be used.

In addition, such investigations should be made as are necessary to give the consumer satisfaction. The points to be given consideration in such investigations are dealt with in Chapter XIII.

Inquiry Tests:

The monthly meter readings should be examined and all abnormal fluctuations in the registration from month to month should be investigated with a view to discovering errors in the meter or other undesirable conditions, and **Inquiry Tests** made when necessary. The registration will usually be subject to certain normal fluctuations, such, for example, as an increase of consumption in winter. Such fluctuations are taken account of by applying a general knowledge of the conditions, and by comparing the registration with that during the same months of previous years (Chapter XIII).

Cases of high registration should be handled in a manner similar to complaints.

In cases of low registration, the work done is only slightly differ-

ent, the emphasis being placed on causes for real, or apparent, decrease in energy consumption, such as a defective, or damaged meter, defective wiring, tampering, absence or removal of consumer from the premises, use of other illuminants, etc.

Repair Tests:

Meters which are damaged, or which develop serious defects in service, should usually be replaced. When, however, the repairs are of a less serious nature, they may be made without removing the meter. Testers carry supplies of the small parts with them, and execute minor repairs in the course of the ordinary testing work. In some cases, it is the practice to employ special repair men, who do not readjust the meter. A subsequent test, known as the **Repair Test,** is then required to place the meter in accurate condition. In character, the test is similar to the installation test and should be made as soon as possible after the repairs.

In the interval, the adjustment of the meter should be so set that there will be no danger of the meter running fast. Induction meters should be returned to the meter laboratory for any repairs involving a change in the lag adjustment unless facilities are available for testing in service on an inductive load.

Check Tests:

Many companies find it advantageous to employ a system of **Check Tests** to insure that the meter adjustment and manipulation are being carried out accurately. Such a system is advantageous as an aid in determining the relative efficiency of the men. Checking is valuable also as a means of encouraging improvements in the work and giving the management greater confidence in the results.

The checks are usually made within twenty-four hours after the original tests, and consist of a verification of the accuracy and an examination of the condition of the meter.

In a large organization, the work is preferably carried on by a group of men detached from the organization. An advantageous arrangement is to employ a man to act as instructor in training the men and also to take charge of checking. Where the size of the organization does not permit this arrangement, the checking may be done by a foreman or by an outside testing authority.

The proportion of each man's tests to be checked varies with the degree of experience and demonstrated reliability of the tester.

Meters chosen for checking should be distributed uniformly between the various types of installation, with the exception that preference should be given to cases where errors are especially likely to occur, such, for example, as meters so installed that it is difficult to make an accurate test.

Meters found outside the limits of adjustment should be readjusted and the matter brought to the attention of the tester concerned.

Referee Tests:

In case of dispute in regard to the accuracy of a meter, a representative of an outside agency is often called in as a referee. The referee may merely witness the tests made by the company, checking the observations and the calculations at such points as he may desire, or the referee may test the meter against an independent set of standards, in which case his standards and those of the company should be connected in circuit and the readings of meter accuracy taken simultaneously. A careful comparison of the two sets of instruments should be made before the test, and if a discrepancy of over 0.5 per cent at any of the loads to be used is found, the error should be located by comparing both sets of instruments with primary standards before proceeding with the test.

No seal should be broken by other than an accredited representative of the company.

Most civic commissions will, upon formal application of any consumer, make a test upon the consumer's meter, under the supervision of the commission's inspector and with the standard instruments of the commission. For such test a nominal fee must be paid by the consumer making application for the test, if the meter is found to be slow or correct within the allowable limits, and by the company owning the meter, if the meter is found to be fast beyond the allowable limit. (See Chapter XIII.)

Inspections:

In practice, cases occur where it is advantageous to obtain an approximate idea of the condition of the meter without recourse to a complete test against accurate standards.

The following approximate methods for obtaining a rough idea of the accuracy of a meter are useful in connection with inspections.

(a) The meter may be loaded by means of lamps whose watt consumption at the normal voltage of the line is known, and timed by

means of a stop watch. This test will be accurate except for errors introduced by deviations in the line voltage from the assumed value.

(b) The meter may be timed on the consumer's load, and a comparison made between the watts indicated by it and the estimated consumption of the consumer's apparatus. Disagreement will indicate either a serious error in the meter or an abnormal condition in the consumer's apparatus.

Installation inspections are sometimes made as an extra precaution prior to the installation test. In the case of small capacity induction meters, the installation inspection may take the place of the installation test.

In such inspections the following points should be observed and checked:

Is the location desirable from the standpoint of effect of dust, dampness, vibration, stray fields and liability of meter to physical damage?

Is the meter supplied with proper voltage, current and frequency?

Is the meter actually connected to the particular load, or installation, the consumption of which it is intended to measure?

Is the meter properly connected?

If the meter is of the polyphase or three-wire type, is it so connected as not to be subjected to reversed torque from one side of the system?

Does the meter creep?

Do the meter number and constants check with capacity and type of meter and the installation records?

Is the accuracy of the meter on light load, as determined by small calibrated lamp, or similar test, approximately correct?

The accuracy of testing and sources of possible errors will now be discussed.

In the **determination of percentage** of accuracy of a watt-hour meter the **timing of the meter** should receive attention.

In order to minimize the effect of **personal errors** and the **stopping and starting errors** inherent in the rotating standard, or stop watch, **each observation** should cover a **period** of not less than 30 seconds.

In tests at light load a period of 30 to 40 seconds will often comprise only one revolution, and it is necessary to use a distinct mark on the disk and to time from the instant that the edge of this mark passes some sharply defined point, such, for example, as the corner of one of the drag magnets.

As to the **number of readings,** at least three determinations should **be made at each load.** When any two of the values of percentage

of accuracy found in the three determinations differ by more than one per cent, the observations should be repeated until three values agreeing within one per cent are obtained. The accuracy reported should be the average of all the readings taken; discarding, however, readings in which a mistake has obviously been made.

When conditions justify it, a narrower limit may be required, but a closer agreement than ½ per cent cannot reasonably be expected. Difficulty in checking indicates variations in the meter under test, variations in the standards or abnormal variations in the testing load. The cause should in all cases be ascertained.

The percentage of accuracy is computed by comparing the corrected readings of the standards and the load indicated by the watt-hour meter, as obtained by the proper formula. The computations are advantageously made on the lower scale of a 10-inch slide rule, which gives results quickly and as accurately as is warranted by the accuracy of the observations.

The expression of test results to a closer degree of accuracy than the observations warrant is to be avoided as misleading. In reporting, the expression of the results to the nearest 0.1 per cent is sufficient, or to record the actual readings of the slide rule, which will be within 0.1 or 0.2 per cent, is permissible. Where a final average is taken, as in complaint tests, the results should be expressed only to the nearest 0.1 per cent.

EXAMPLE 1. A meter of the following description is tested at full load, with the results given below:

Two-wire, 110-volt, 10-ampere meter

Watt-hour constant (K_h)	$=0.5$
Watt-second constant (K_s)	$=1{,}800$
Revolutions timed (R)	$=20$

	First Observation	Second Observation	Third Observation
Voltmeter indication	111.5	111.0	111.8
Correction of voltmeter	—0.4	—0.4	—0.4
True volts	111.1	110.6	111.4
Ammeter indication	9.55	9.53	9.57
Correction to ammeter	+0.02	+0.02	+0.02
True amperes	9.57	9.55	9.59

	First Observation	Second Observation	Third Observation
True watts	1063.0*	1056.0*	1068.0*
Seconds indicated by stop watch	34.7	34.8	34.6
Corrections to stop watch	+0.1	+0.1	+0.1
True seconds (S)	34.8	34.9	34.7
Meter watts $= \frac{K_sR}{S} =$	1,034*	1,032*	1,037*
True watts $= W =$	1,063*	1,056*	1,068*
Percentage of accuracy of meter $= \frac{1034}{1063} \times 100$	97.3%	97.7%	97.1%

Average....97.4%

Example 2. The calculation shown in Example 1 may also be carried out as follows:

Meter watt-seconds $= K_sR = 1{,}800 \times 20 = 36{,}000.$

True watt-seconds $= WS = 1{,}063 + 34.8 = 37{,}000^*$ $\quad 36{,}850^*$ $\quad 37{,}060^*$

Percentage of accuracy of meter $\frac{36{,}000}{37{,}000} \times 100 = 97.3\%$ $\quad 97.7\%$ $\quad 97.1\%$

Average (at given load)....97.4%

Or as follows,

$$\text{Percentage of accuracy} = \frac{K_sR}{WS} \times 100 = \frac{1{,}800 \times 20}{1{,}063 \times 34.8} \times 100 = 97.3\%$$

$$= \frac{1{,}800 \times 20}{1{,}056 \times 34.9} \times 100 = 97.7\%$$

$$= \frac{1{,}800 \times 20}{1{,}068 \times 34.7} \times 20 \times 100 = 97.1\%$$

Average....97.4%

*To nearest 0.1%

To eliminate personal errors, select proper standards. Do not attempt to use instruments built for continuous current measurements on alternating current work.

An induction standard should be used only on a circuit having a frequency for which the standard is built.

The use of standards so large that readings will be taken at small percentage loads should be avoided. Standards of doubtful accuracy should, of course, never be used.

Incorrectly reading scales of instruments, rotating standards, or stop watches, may introduce a large error in final results. The remedy is to become thoroughly acquainted with the value of the divisions in the units of what is attempted to be measured. This precaution is particularly applicable to instruments having two or more ranges, where the value of one division will be different in each range. Practice reading correctly to tenths of divisions.

The proper precautions should be taken to avoid parallax errors.

Where the line voltage or load is fluctuating, care should be taken to properly average values. The correct value is the time average, rather than the average between the highest and lowest values. A large deviation from the average deflection for a small time may have no more effect than a small deviation for a longer time. In other words, each reading of the indicator should be given a weight depending upon how long the pointer remains at that deflection.

For example, if the indicator of a voltmeter remains at 110 during the first 20 seconds, and at 111 during the remaining 20 seconds of a 40-second reading, the average is 110.5. If the indicator remains at 110 during the first 5 seconds and at 111 during the remaining 35 seconds of a 40-second reading, the average is

$$\frac{(5 \times 110) + (35 \times 111)}{40} = 110.9.$$

In an ordinary case in practice, a rapid succession of readings would give a large variety of deflections, varying by a few tenths of a per cent, so that a certain calculation like the above would be unwarrantably tedious. The average deflection is therefore usually obtained by estimation, bearing in mind the above principle.

Accurate results can be obtained only by taking the average of a sufficient number of independent readings. Where abnormal variations occur, the tests should be repeated until consistent results are obtained.

Improper and poor connections may introduce very serious errors. When testing meters or instruments, be sure that neither the standard or the one being tested measures the potential circuit energy of the others. Be sure to have the same voltage impressed upon the standard and the apparatus to be tested. Be sure that there is no current diverted, between apparatus to be tested and the standard. In watt-hour meter testing this diversion may be to, or by, test lamps,

pilot lights, consumer's load or leaks through faults in leads and testing apparatus. All electrical connections should be clean and free from grease and should have a proper amount of bearing pressure. This applies particularly to leads between millivoltmeter and shunt on account of the "drop" across the shunt generally being but a small fraction of a volt.

Millivoltmeter leads should not be changed without recalibrating the instrument with the new leads. Care should be taken that there is no leakage of current between millivoltmeter and shunt and that there is no break in the leads, or strands of the leads.

Failure to recheck at full load after changing light load adjustment may introduce an error which will leave the meter outside of the limits of accuracy aimed at.

Absence of, or incorrect, diagnosis of abnormal conditions in a meter may cause an error to appear some time after a test is made. This might be caused by short circuits in commutator, series resistance or series impedance which may afterwards clear themselves and cause meters to have errors, on the fast side, which they did not have when tested. Meters adjusted with small particles in them which may change position and thus vary the friction, may cause the meter to register either "fast" or "slow," especially at light loads.

Failure to allow the potential circuits of some types of meters (especially commutator types) to come to the proper temperature, after being out of circuit, will give results which indicate that the meter is faster than it really is under normal operating conditions.

Errors of starting and stopping are not always in the same direction, but may be positive at starting and negative at stopping, or vice versa, or may be accumulative.

Only by considerable practice in starting and stopping rotating standards and stop watches and determining the exact instant when a mark on the moving element passes a fixed mark, can these errors be reduced to a minimum.

Results of the tests should be calculated with care. Greatest attention must be used that the proper test constant is utilized. A formula and method that involves as few operations as possible should be selected.

When using a slide rule, thorough acquaintance with the scale is necessary, if errors are to be avoided.

To avoid errors in noting results on test forms, this work should be done at the time and place where the test is made. As progression is made from one step to another in the work, the form should be carefully and accurately filled out.

Inherent errors in instruments have, of course, direct bearing on the tests.

A **zero error** is that error due to the indicator not returning to zero when the force causing it to deflect is removed. Most instruments will allow the indicator to be reset to zero without appreciably changing the calibration, and some instruments have a special device for setting to zero without removing the cover. If the scale is uniform the zero error can be estimated or measured and allowed for. Where the scale is not uniform it is a difficult matter to make the proper allowance.

If the **scale is improperly divided**, the per cent error will vary at different points, and an accuracy curve should be used with the instrument.

When the indicator of an instrument is sluggish, due to friction, the indication is liable to be either too high or too low and may cause a variable zero error.

This error can be detected by tapping the case gently with the fingers, and if found to exist, the instrument should be returned to the company's laboratory for correction.

If the movable element is **not dead beat** the swinging motion, due to small fluctuations, will not allow exact readings to be taken.

Static charges will sometimes cause an indicator to indicate when not connected in circuit. If the glass in the cover of the instrument is cleaned just before using, it may become statically charged and cause the indicator to deflect. Blowing the breath on the window or touching it once or twice with damp fingers will generally remove the charge.

When making tests upon high voltage circuits, one of the greatest sources of error is that produced by a static charge, which causes the instrument to appear sluggish or erratic, or causes the needle to deflect above or below zero before the circuit has been completed.

This source of error can usually be eliminated by the application of the suggestions made in Chapter V for the same conditions, the same precautions against personal injury and damage to voltmeters or wattmeters being observed as were proposed there.

Temperature errors are those errors due to changing of temperature in parts of the instrument due to either or both outside or inside influence. Readings will not only vary with varying temperature of surrounding atmosphere, but may have large errors due to continued passage of current through them.

There are two sources of errors in shunts due to temperature, viz.,

change in resistance and thermoelectric effect. These errors should be carefully guarded against by using shunts of low temperature coefficient metal, and by being careful that one end of a shunt is not heated to a higher temperature than the other end. The **electrical connections** at each terminus should be equally good. The metal of the shunts should have a low thermoelectromotive force against copper.

Some **current transformers** are built so that the **ratio** can be changed by changing the arrangement of some plug or link connections.

To avoid **errors** in using these transformers, the plugs or links should be in the primary circuit and care should be taken to place them in their proper places for the desired ratio. A misplaced plug or link will cause a large error.

Errors may arise **from the use of low voltage potential transformers,** for obtaining load, under certain conditions.

Some **shunts** are so constructed of multiple leaves that the leaves return upon themselves, separated by thin slabs of insulating material. If this insulation drops out it may allow the blades to **short circuit,** thus lowering the resistance of the shunt. Again, there is placed in some multiple range portable shunts, adjusting resistances in series with the millivoltmeter. If any portion of these becomes short circuited, it will produce a reading of the millivoltmeter which is too high.

If the **resistance material** has an appreciable temperature coefficient, **errors due to the change in temperature** caused by the flow of current might be considerable and indeterminate, due to the fact that the temperature would be difficult to measure.

The constant heating and cooling of the resistance material is also liable to cause changes in the resistance. Then, too, as the leads are considered part of the resistance, a fault in these may introduce serious errors.

If **calibrated resistances** are to be used **for alternating current testing,** they should be **non-inductively wound,** otherwise the true value of wattages corresponding to the voltmeter readings will be too low.

The **inherent errors in rotating standards** are principally as follows:

Changes of temperature will generally produce slight changes in the accuracy of rotating standards. This error is not large, but if the rotating standard is to be used in temperatures varying widely from that at which it was calibrated, it would be well to know just how much effect the temperature will have on the particular rotatin standard to be used. The resistance of potential circuits of conti

uous current rotating standards changes with the rise in temperature due to current passing through them. It is therefore necessary to use the rotating standards after this temperature has become constant or that some temperature correction device be used.

Inertia of moving element in starting and stopping sometimes causes errors. These errors occur in the potential switch method, but are absent in a method where continuous rotation is used. It has been discovered that the loss of revolutions in starting is generally greater than the gain in stopping, but this error is small enough to be practically negligible in commercial meter testing.

Some switches introduce errors by acting slower when turned off than when turned on or vice versa.

Stop watch errors should be guarded against. These errors are discussed in Chapter V.

Continuous current instruments often are used in such places that a considerable error is introduced due to **effects of stray magnetic fields.** These errors may be either positive or negative in their effect. If the deflection is steady the presence of such fields may be detected by turning the instrument (horizontally) through 180 degrees.

The stray field may be introduced by conductors carrying current; other instruments; motors; masses of iron; rheostats; other electrical apparatus, or the earth's field. Hence, instruments should be set up far enough away from these things that the effect of the stray field will be negligible. Packing boxes may contain iron, and should be avoided as a place on which to use instruments, unless their contents are known not to consist of material with magnetic characteristics. Strong magnetic fields will sometimes not only produce errors in measurements, but may change the strength of magnets and hence permanently alter the accuracy of an instrument. Instruments of the dynamometer type are generally more sensitive to stray fields than those of the D'Arsonval type and almost invariably should have readings taken upon reversed polarity, and the mean of the two readings taken as the true reading. Some instruments are shielded by iron cases or separate iron shields or boxes and, when so shielded, it takes a field of considerable strength to introduce appreciable errors. (See Chapter IX.)

Instruments used on alternating current are affected by magnetic forces in a manner similar to those of continuous current, but the magnetic fields producing errors must be alternating and of the same frequency as the current being measured. Unidirectional stray fields have practically no effect on their accuracy.

Continuous current rotating standards are affected by stray fields in a manner similar to continuous current instruments. They should always be set up with the plane of their current coils parallel to the lines of force of the stray fields. (See Rotating Standard Method of Testing in Chapter VIII.)

Alternating current rotating standards of the induction type are very little affected by stray fields, but care should be taken to keep them away from conductors carrying heavy alternating currents, alternating current motors, transformers and other apparatus. A strong field, either alternating or continuous, may cause the rotating element to run slow, due to the extra drag on the disk or cup.

Service watt-hour meters quite frequently come within the influence of stray magnetic fields. It is practically impossible to reverse the polarity on most commutator type meters and still preserve accuracy. The earth's field alone has an appreciable effect on light loads. Meters can generally be adjusted to compensate for the effect of stray fields, but there is seldom the assurance that the stray field will remain constant. The leads to the watt-hour meter may be in such a position that the field set up by the passage of current will alter the accuracy of the meter. Care should be taken, therefore, in the arrangements of jumpers and testing leads that a different field is not set up than there is under actual operating conditions. This applies particularly to large capacity meters.

Avoid setting meters so close together that one meter affects the registration of another. Meters placed close to masses of iron will sometimes magnetize the iron to such an extent that an inaccuracy is introduced. This is liable to occur where the heavy current due to short circuit has passed through a meter, setting up momentarily a large magnetizing force.

It will be seen that there are many sources of error and that there is no assurance of one error being compensated by another. Therefore it is necessary to be constantly watchful, if final results are to have a minimum error. Hard and fast rules cannot be set down for all cases, but in each case it will probably have to be determined where errors might occur and proper precautions taken to avoid them.

In testing continuous current watt-hour meters on consumers' premises, the order of work given below applies to meters having the most common arrangement of parts, that is, with the weight of the moving element supported on the lower bearing, and the commutator and register near the top bearing.

In Commutator Type Meters:

1. After the test "as found," clean the meter thoroughly, removing any dust or dirt which may have collected.
2. Remove and examine the register, first having recorded its reading.
3. Clean the top bearing.
4. Clean the commutator and brushes.
5. Examine the step bearing.
6. Adjust the height of disk. Examine magnets for filings and clean.
7. Test the level of the meter and correct or report.
8. Adjust the brush tension.
9. Reset and replace the register and see that it meshes.
10. Before calibrating the meter, blow or brush out thoroughly to remove dirt that may have resulted from cleaning the various parts.
11. Clean the cover thoroughly and examine for holes before replacing.

The adjustments of a meter are those made at full load and at light load.

The **full load adjustment** is obtained in most meters by changing the position of the drag magnets or by varying the amount of flux passing through the disk. The change produced in the percentage accuracy is substantially the same on all loads; that is, if the accuracy is 95 per cent at both full load and light load, shifting the full load adjustment so as to increase the speed 5 per cent will make the meter approximately correct at both loads.

The **light load adjustment** is obtained by varying the amount of the friction compensating torque. The effect of this is inversely proportional to the load; that is, twice as much at 5 per cent load as at 10 per cent load; one-tenth as much at full load as at 10 per cent load. For example, if a meter is 1 per cent slow at 100 per cent load and 10 per cent slow at 10 per cent load, shifting the light load adjustment to correct the error at light load will also correct the error at full load. When the tester knows that the light load adjustment will have to be shifted by a large amount, he can save time making an allowance for it in his first setting of the full load adjustment.

Generally, when a meter is found inaccurate, the cause is some condition in the meter which should be removed rather than compensated for. In such cases the tester should always locate the trouble, and the adjustments should not be shifted unless the meter is still accurate after going over all the parts and restoring them to per-

fect condition. **The principal troubles** to be looked for under various conditions are given in the following table:

COMMUTATOR TYPE METERS

METERS FOUND	LOOK FOR
Slow. Full load and light load	Short or open circuit in armature; short circuit in commutator; incorrect angle between the coils and the commutator; short circuit in current coils; loose magnets.
Slow. Principally at light load	Defective bearing; rough commutator; too much brush tension; iron filings on magnets; other causes of friction; stray fields; loose light load adjustment.
Fast. Full load and light load	Weakened or loose magnets; short circuits in series resistance.
Fast. Principally at light load	Too little brush tension; stray fields; loose light-load adjustment; vibration.

Causes of Inaccuracy.

To save time in **making adjustments,** the tester should learn, by experience, how much shift is required for a given percentage change.

In meters where the full load adjustment is obtained by moving the magnets, a small movement has a considerable effect on the accuracy, and care is therefore required to obtain the correct adjustment. Leaving the clamp screws tight and forcing the magnets by prying with a screw driver or other implement is not permissible, as the meter may be injured. If the screws are entirely loosened, the magnets are apt to be shifted while tightening them. The best method is partially to tighten the screws so that the magnets may be moved without much difficulty and yet will stay where they are put. A special wrench for moving the magnets is sometimes used. The screws should be thoroughly tightened before the final recheck readings are taken. In meters having micrometer adjustments, th

micrometer screws are not to be depended upon to keep the adjustment permanent and the set screws should be carefully tightened.

The effect of either an **open circuit** or a **short circuit** in an armature coil is to cause the meter to run slow. Various possible conditions are shown in Figs. 246 to 249.

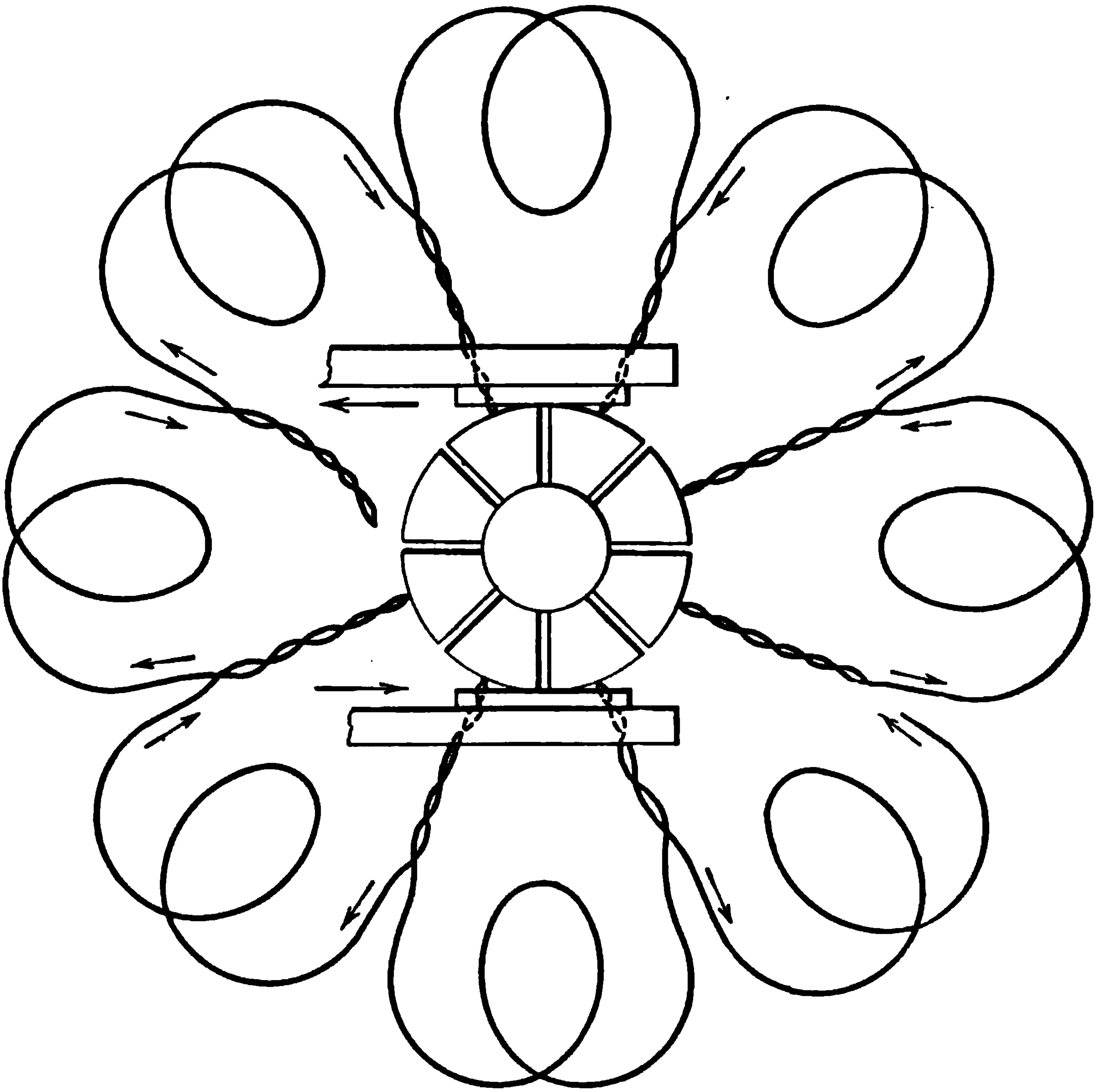


FIG. 246.—Armature with Leads Disconnected from Commutator Bar.

If the lead running from two of the coils is disconnected from the commutator bar, as shown at Fig. 246, then when either brush rests on the bar, there is no circuit through the armature and the meter will not start. If a single coil is open, as shown at Fig. 247, only one-half the ›ils will be in circuit, but each will receive the total current. On

account of the increased resistance of the armature, the current is reduced, causing the meter to run slow but with a uniform speed.

The effect of two open circuits in the armature is shown in Fig. 248. During a part of the revolution current passes through one-half of

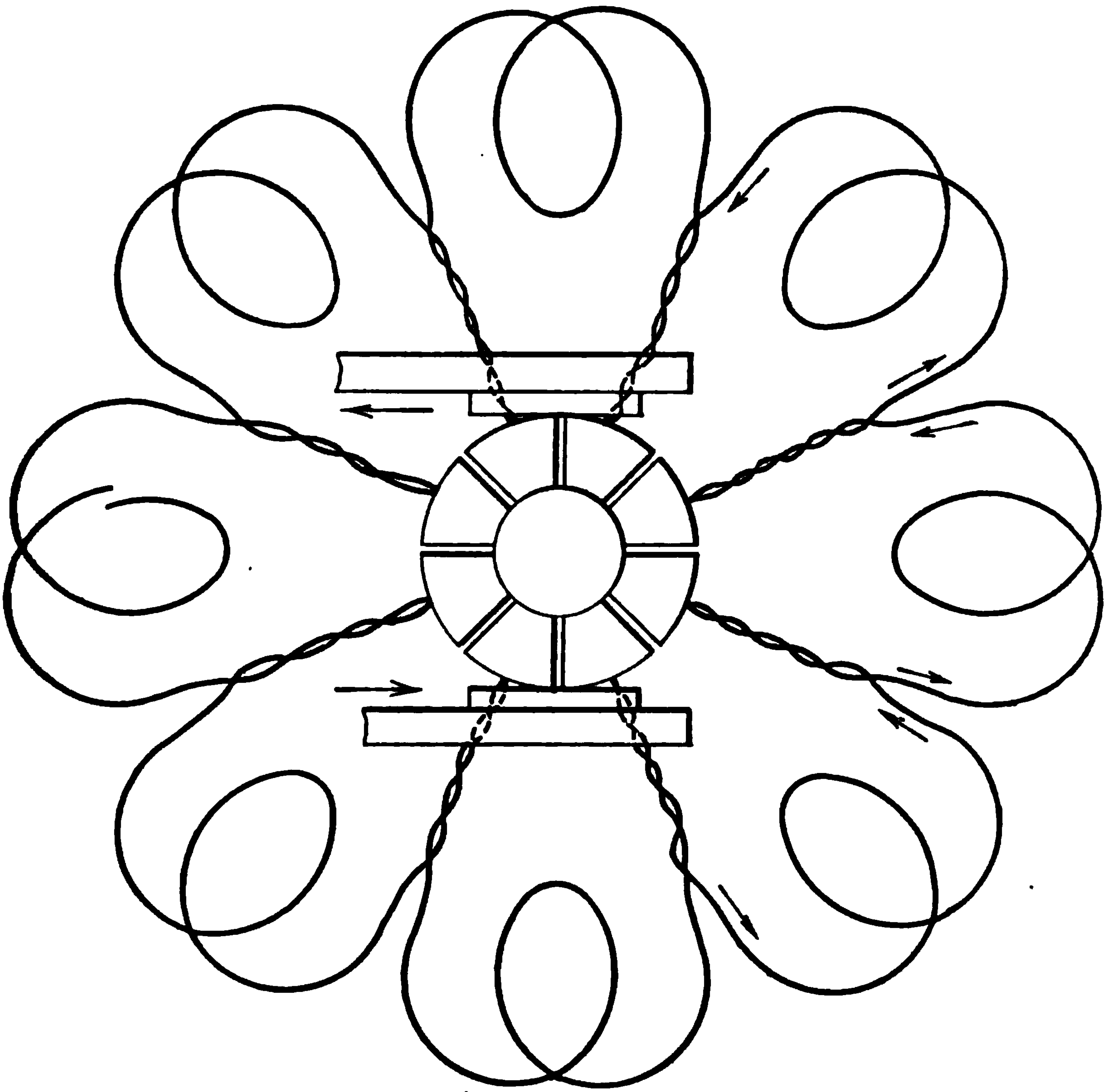


FIG. 247.—Armature with Open Circuit in One Coil.

the armature only, and for the remainder of the revolution the circuit is open and the meter will stop.

A short circuit between two commutator bars or in a coil, as shown in Fig. 249, will make the coil inactive in all parts of the revolution. thus reducing the torque and causing the meter to run slow.

Tests for Defects.

The usual **tests for defects in the armature** are as follows:

(a) A pair of metallic points (Fig. 250) connected to a voltmeter may be placed in contact with adjacent commutator bars. The same

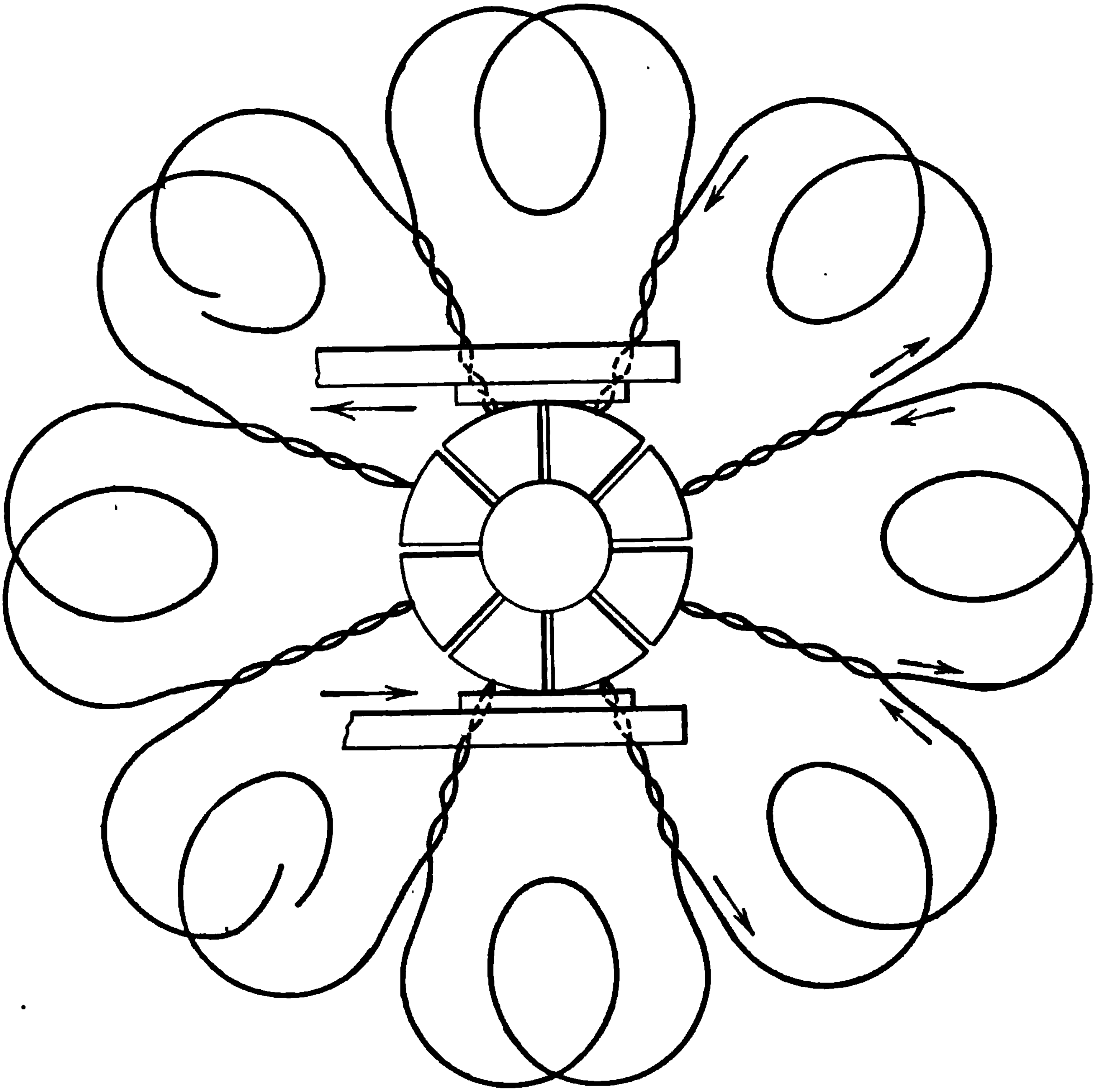


FIG. 248.—Armature with Open Circuit in Two Coils.

drop should be obtained across each coil. A short circuit will give lower and an open circuit higher than the normal voltage. The points should touch the bars near the end, so as not to roughen the part of the commutator on which the brushes bear.

(b) A voltmeter may be connected to the brushes and the ob-

served drop compared with the correct drop for the given type of meter. If a lead is disconnected from the commutator bar nearly full-line voltage will be obtained when this bar is under the brush. An open circuit in a coil will give nearly double the normal voltage. Short circuited coils will reduce the voltage.

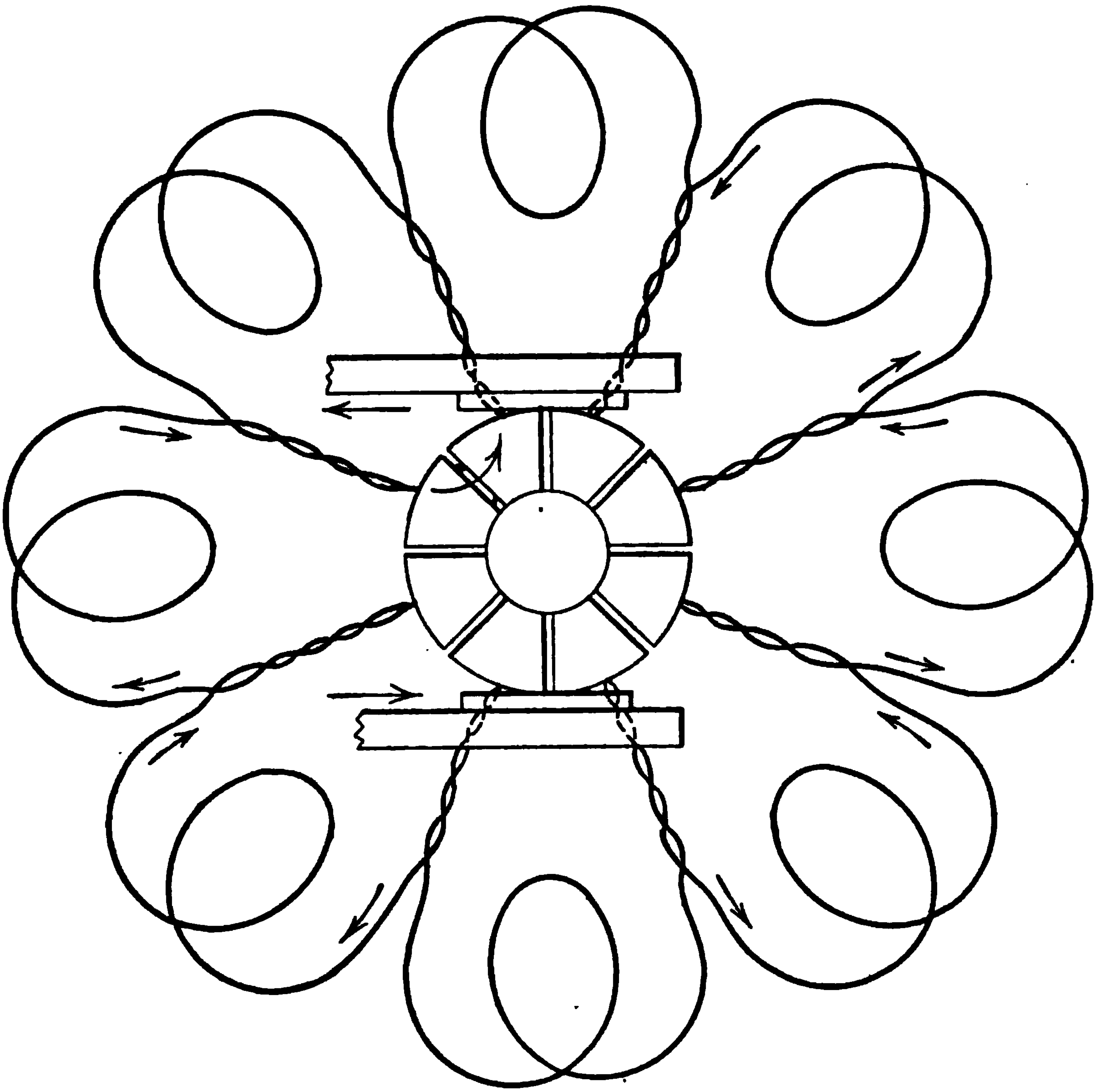


FIG. 249.—Armature with Short Circuit between Two Commutator Bars.

(c) A lamp or voltmeter may be used for detecting a short circuit or an open circuit by connecting it to the line in series with the injured part and judging the amount of resistance by the decrease in voltage. In making this test on the commutator, the regular connections of the voltage circuit to the line must be removed.

Short circuits and open circuits often occur **at the commutator,** in which case they are ordinarily easily repaired. If the defect is in the winding itself, the armature must be replaced.

Commutator and Brushes.

The **commutator and brushes** are the most sensitive part of the meter, and must be kept in the best possible condition.

Aging.

When the commutator and brushes are properly adjusted and the meter operates under ideal conditions, the rate of wear is very small. After the contact surfaces have been worn together, a condition is reached where, if the commutator and brushes are undisturbed, the amount of friction is constant. The commutator bars and the parts of the brushes which rest on them are ordinarily made of silver,

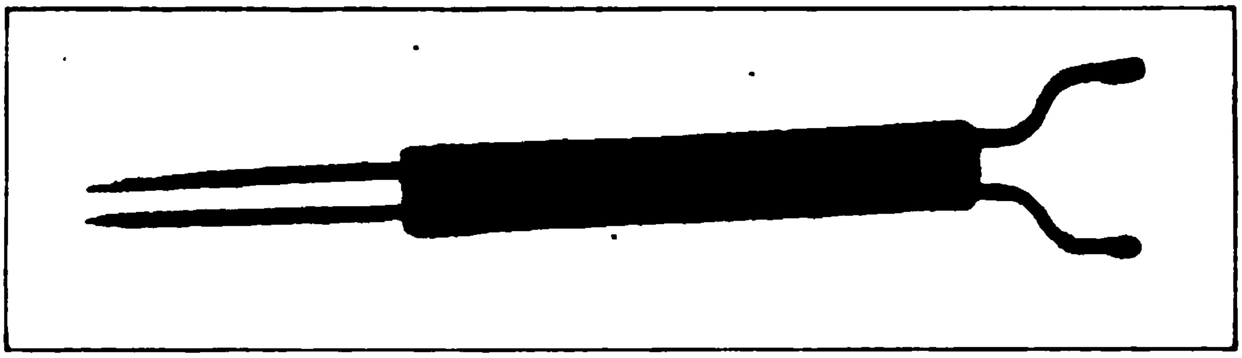


FIG. 250.—Metallic Points for Testing Commutator with Voltmeter.

which gradually becomes tarnished with a coat of silver sulphide, due to the trace of sulphur which is always present in the atmosphere. The sulphide is a conductor, but causes a slight increase in friction, making the meter run slower on light load, so that in silver commutators the aging is dependent on the tarnishing as well as on the wear.

The aim of commutator work is to produce and maintain this permanent tarnished condition, and when in proper condition the commutator and brushes should be disturbed as little as possible.

The time required for complete aging depends largely upon local conditions. The period between the installation and the first test of the meter is probably not always long enough for complete aging, but, due to other conditions, it is not advisable to increase this time.

Wear.

When the commutator and brushes are properly aged, what wear does occur will be mainly at the surface of the brush, which may eventually become hollowed out to fit the cylindrical surface of the

commutator. If the surfaces remain smooth, a moderate amount of hollowing will do no harm; but, if allowed to go on too long, it may affect the accuracy, short circuiting the armature coils.

Sparking.

The chief source of wear is sparking at the brushes, which is caused by vibration, insufficient brush tension, dirt or dust, or roughness in the contact surface.

If from any of these causes the brush is momentarily raised from the commutator, this opens the potential circuit and the full voltage of the line becomes active at the point of separation, establishing a miniature arc, burning a pit in each of the surfaces. The metal melted out runs to one side and forms a lump over which the brush will have to ride at every revolution, repeatedly opening the circuit and eventually roughening the commutator over its entire surface.

The damaging effect of sparking is reduced by some of the roughness wearing smooth again, but a condition where the friction is constant is never reached. Generally the commutator gets worse and worse the longer the trouble goes without remedy. If the tester shifts the light load adjustment to overcome the excessive friction, subsequent wear may decrease the friction and cause the meter to run fast.

When a commutator shows pitting or roughness due to sparking, the surface should be cleaned and polished. This is necessary, since the commutator reaches the proper condition of aging only when it starts from a smooth surface.

A commutator should never be left sparking. Absence of sparking at the time of test is not a guarantee that it will not set in later, unless the brushes are set to withstand the more severe conditions of vibration, dust, etc., which the meter may later undergo.

Vibration.

Where a meter is subject to **vibration** the brush tension should be increased, to reduce the liability of sparking. This increases the friction and requires a greater light load compensation, but it is better to have a large amount of friction which is constant and can be compensated for than to allow sparking, which results in a variable friction.

Cleaning of Commutator.

The **commutator** should be **cleaned** out thoroughly with the air syringe or with a camel's hair brush to remove whatever dust or dirt may have collected on it. The breath should never be used o

any part of the meter. Dirt which adheres may be removed, without entirely destroying the tarnish, by means of a narrow strip of linen tape, subsequently brushing or blowing out the loosened particles.

Where a commutator is roughened by sparking, it should be polished by means of a narrow strip of worn crocus cloth about one-fourth of an inch wide. New crocus cloth should not be used until it is worn smooth on some hard metal object, to remove all loose particles of grit which might work into the surface of the commutator, and care should be taken not to lay the crocus cloth down in locations where it may collect dust. The worst roughness is usually found at the edges of the commutator bars, and the polishing should go on until the entire surface is smooth. After using the crocus cloth, the commutator should be given a final polish with the linen tape. In using the crocus cloth and tape, the tester should be careful not to use enough force to bend the shaft. A light, quick stroke, crossing the tape so that it clings to the commutator, giving the armature a spinning motion, gives the best results.

In the interests of safety, the voltage circuit should be disconnected from the line when adjusting and cleaning the commutator and brushes. It should be immediately reconnected, so that the meter will be properly warmed up during the final readings.

Dust lodged between the commutator bars sometimes causes short circuits between adjacent bars, or from one bar to the shaft. These short circuits may be located by the methods given under "Armature" and "Insulation." Where the dust is caked so that it cannot be blown out or brushed out, it may be dug out by means of a pointed tool known as a commutator pick. Several forms of this tool are shown in Fig. 251. Such tools must be used with very great care to prevent raising a burr at the edge of the commutator bar.

Short circuits may sometimes be burned out by connecting the commutator to the line in series with a lamp.

In the smaller commutators used in most modern meters there is less friction, and therefore the effect of aging and of a given amount of roughness is smaller. On the other hand, the effect of a short circuit between two segments is the same when the same number of segments is employed. On account of the small size, it is more difficult to remove short circuits. As far as their size permits, these commutators are treated the same as the larger commutators.

Summary.

The above may be compiled as a **summary.**

1. If a commutator is smooth, clean out dust with an air syringe

or with a camel's hair brush, using the linen tape if necessary, but removing as little of the tarnish as possible.

2. If pitted and roughened by sparking, polish to a true surface with worn crocus cloth, finishing with linen tape and blowing out dust with the air syringe. Dirt caked between the segments should be removed before polishing.

3. Adjust brushes.

4. If, after these adjustments, the commutator still sparks, first use the brush or air syringe again to be sure that all dust is re-

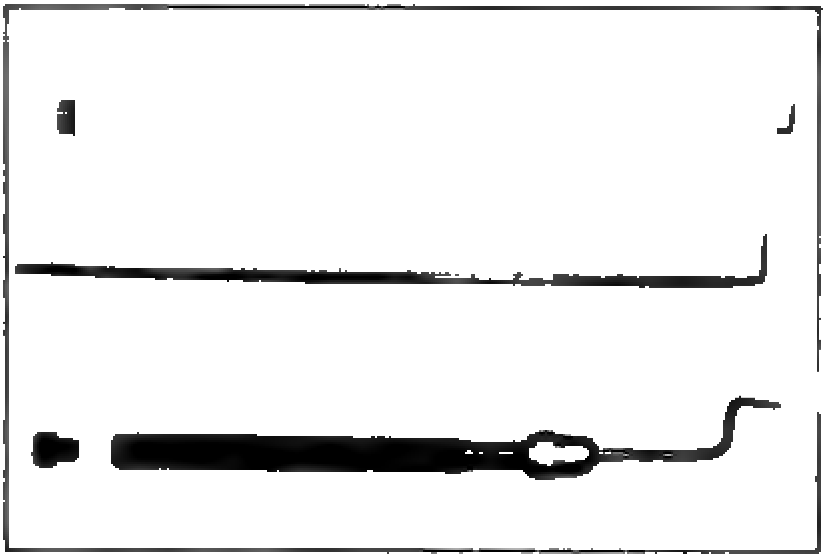


FIG. 251 —Commutator Picks.

moved. Examine the brush tension. If the sparking is due to vibration, the brush tension may be increased. Never leave the commutator sparking.

Flat Spring Brushes.

Watt-hour meters with brushes having a flat-bearing surface are more liable to commutator troubles and more difficult to maintain than those employing round brushes and all of the above directions must be carefully followed.

The tension of both brushes should be the same. For **adjusting brush tension** two rules are in common use:

(a) The brush should not vibrate or "jingle" when sprung about $\frac{1}{8}$ inch from the commutator and allowed to fly back into place. (b) On lifting one leaf of the brush from the commutator it should move $\frac{1}{16}$ inch (or twice the thickness of the end of the brush) from the commutator before the other leaf leaves the commutator.

The tension of both leaves of each brush should be the same, and

each should bear flat on the commutator. The contact surfaces should be parallel, so as to touch the commutator at diametrically opposite points. When sprung back from the commutator by pressure applied to the brush back of where it is divided, the two leaves should lie in the same vertical plane.

Brushes which have become roughened are polished with smooth crocus cloth glued to a flat piece of hard wood. Where the brush has a groove too deep to remove in this way, a fine flat file (No. 4 fineness, 4 × ½ inches with blank edges) is used first and the crocus cloth afterwards. If any difficulty is experienced in getting a true flat surface on the brushes, they should be removed from the meter and held against a fixed support while filing.

The brush tension may be adjusted either by twisting the brush-stud in its bearing by means of the brush-stud wrench, or by changing the amount of the permanent set in the spring where it coils

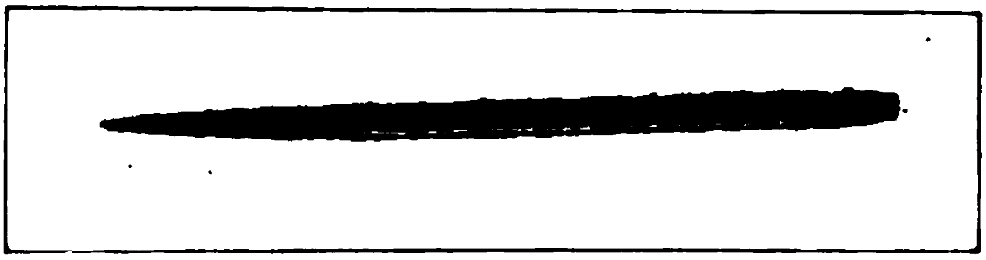


FIG. 252.—Brush Tool.

around the stud. In the latter method, to increase the tension the brush tool (Fig. 252) is held parallel to the brush and its end pushed in between the brush and the stud. To decrease the tension, the brush is sprung back from the commutator by holding the tool against it near the stud. The slotted end of the tool is used to twist the ends, when necessary to make them lie flat on the commutator.

After these adjustments have been completed, it is advisable to press the brushes against the commutator and rotate the moving element a dozen or so times, in order to seat the surfaces together before taking the final readings.

Gravity Brushes.

In **gravity brushes** the tension is obtained by means of a weight and is therefore very uniform. It may be adjusted by moving the weight in and out along its arm. It is not customary to file the brushes, which are allowed to run until worn out, when they are replaced.

Some manufacturers are prepared to furnish gravity brushes to replace the flat spring brushes on their older types of meters.

As the armature rotates, the current in each coil should reverse

when the coil is parallel to the current coils. Each coil is connected between two adjacent commutator bars, and the reversal takes place at the instant when the brush passes from one bar to the next.

Fig. 253 shows the **correct relation of brushes and commutator** for a meter whose brushes are at right angles to the plane of the field coils. In a meter whose brushes are parallel to the field coils, as

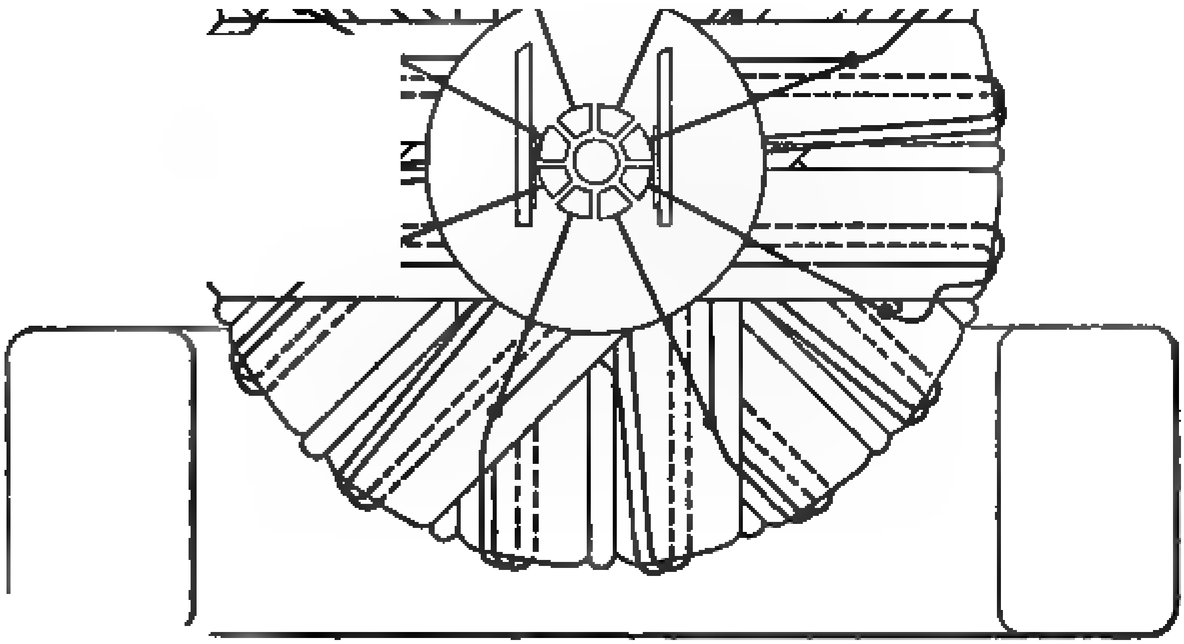


FIG. 253.—Relation between Commutator and Armature when Brushes are at Right Angle to the Current Coils.

shown in Fig. 254, the commutator when correctly placed is twisted 90 degrees from the position it has in the other meters.

When the angle is not correct, each coil is reversed too early or too late. During part of the revolution, it furnishes torque which opposes that of the other coils, causing the meter to run slow.

Short Circuit in Current Coils.

In those meters having two current coils this defect can be detected by testing the meter on each coil separately. The meter will run slower with same load on the **short circuited current coil** than on the perfect one.

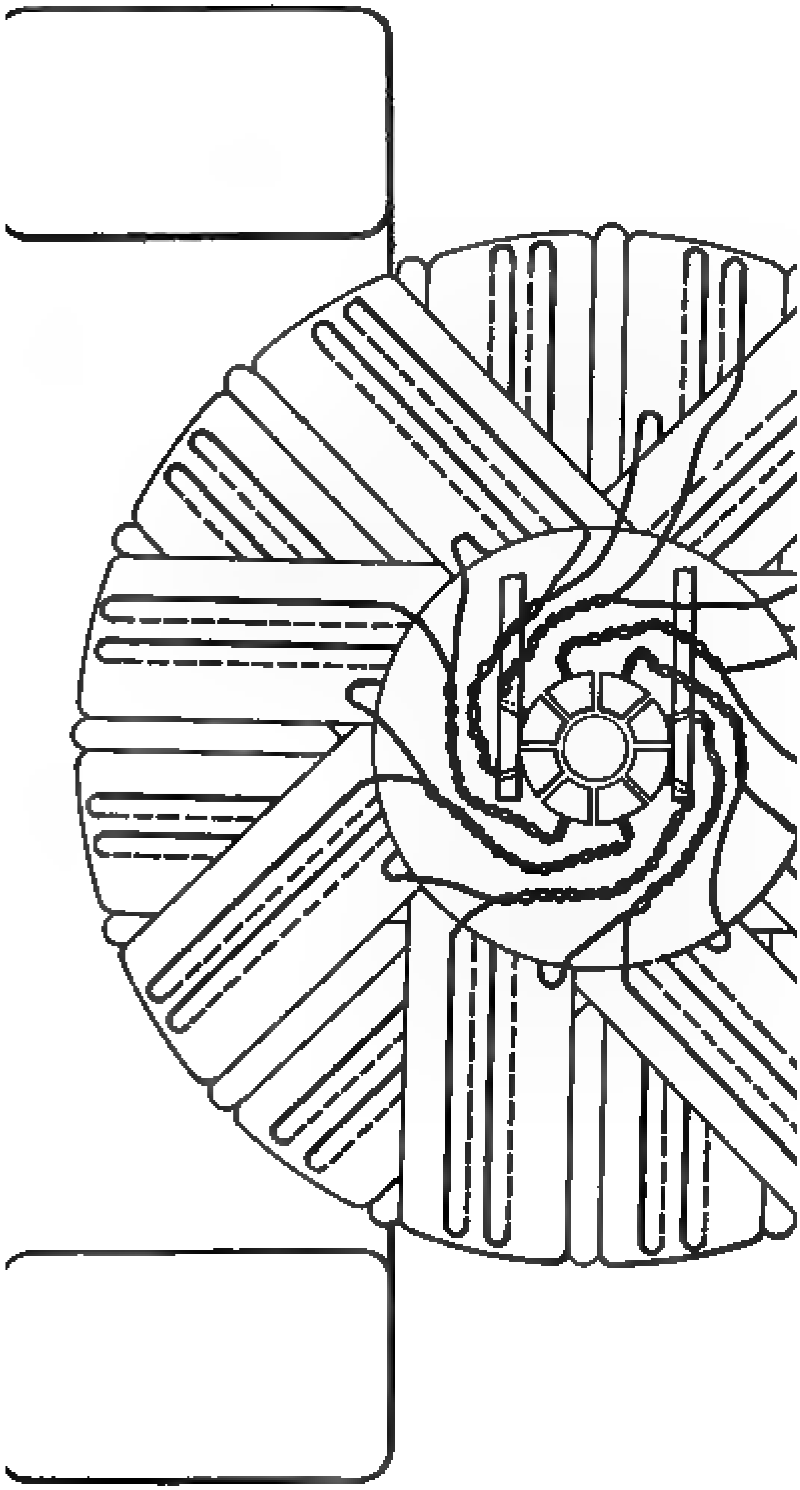


FIG. 254.—Relation between Commutator and Armature when Brushes are Parallel to the Current Coils.

Loose Magnets.

A magnet that is left or has become loose is liable to work out of place, thus varying the "drag" on the disk and causing the meter to register either too fast or too slow.

Top Bearings.

If **bearings** become **defective** they generally increase the friction and consequently cause the meter to run slow. The effect of this would be about ten times as great at one-tenth load as at full load.

Following will be given a description of most of the more common **bearings** and how to treat them.

The function of the **top bearing** is merely to hold the moving element centered. The top bearing is ordinarily not much affected by wear, and does not require as much attention as some parts of the meter, but the following practical points should be looked after.

The top bearing employed in the majority of meters has the shaft turned down to fit loosely into a small hole in the top bearing stud. This hole should, when necessary, be cleaned out by means of a small strip of wood. The splinters or orange wood used by jewelers for similar purposes are recommended. If the upper end of the shaft is dirty, it may be cleaned by means of a linen tape or a split piece of soft wood. If rusted, it may be polished; but, ordinarily, if rusted too badly, the meter should be replaced. Oil should never be used in top bearings of this type, as it is apt to run down on the worm and form a gum, increasing the friction.

The top bearing used in some of the recent meters differs from the type described above in that a stationary pivot is used which projects into a hole in the shaft. The bearing is self-oiling, an oil-saturated disk being placed at the bottom of hole.

The top bearing should be set high enough to prevent excessive friction, but not so high that the shaft will slip out of the bearing when the moving element is pushed down as far as it will go. After adjusting the top bearing, examine the worm or pinion to make sure that it meshes properly.

Step Bearings.

The **step bearing** ordinarily consists of a stationary **sapphire or diamond jewel** with a **steel pivot** on the moving element, or of two jewels with a steel ball rolling between them.

The **sapphire jewel** should be removed from the meter, cleaned and examined at every test, and, if found defective, should be replaced. The common method for testing a jewel in service is to employ a fine, sharp needle which is held loosely between the fingers and its point moved back and forth over the surface of the jewel. By this method, a very slight roughness may be felt, but, if there are only a few rough spots on the jewel, the needle may miss them.

In periodic tests on commutator meters it is better practice to

replace all jewels and return them to the laboratory, where they are assorted by microscopic examination, those still smooth being again used, and those rough, repolished or discarded.

Diamond jewels are more expensive than sapphires, but are much more durable, so that in cases where sapphire jewels would have to be replaced frequently it not only gives better accuracy, but is more economical to use diamond jewels.

Diamond jewels should be examined at every test, but the needle examination is not so reliable as for sapphires, since the depressions worn in the surface of the diamond are frequently smooth and do no harm. Diamond jewels need not be replaced unless the accuracy of the meter is such as to show excessive friction. Unless cracked by a severe blow, they will generally survive a number of testing periods before replacement.

Microscopic Examination.

The best method of distinguishing perfect from imperfect jewels in the meter shop, or laboratory, is by **examination with a binocular microscope** of moderate power (about 50 diameters magnification). All apparent roughness should be gone over with a needle while the jewel is held under the microscope, as they often prove to be only particles of dirt on the surface. The examination should be made by an expert; a novice is likely to be deceived by reflections from the surface and by the transparency of the jewel, which allows its rough bottom to show through.

Pivots and Balls.

Pivots and balls used with sapphire jewels should be replaced when replacing the jewels, since, if the latter are rough, the former are sure to have been damaged. Where the jewel is still perfect, the pivot or ball is often worn, and it should, therefore, always be examined. Wear on pivots or balls can be detected by examining with a magnifying glass or microscope, by observing the reflection on the surface from a lamp or other sources of light, or by rubbing on the thumb nail.

Pivots running on diamond jewels should be replaced at every periodic test. The cost of repolishing pivots is so low that it does not pay to sort them, and they are generally all repolished without regard to appearance.

Steel balls and pivots should be protected from rusting and should not be touched with the fingers. Keeping them under oil is usually unsatisfactory, on account of the difficulty of obtaining oil which is

absolutely acid free. They should preferably be kept in talcum powder.

The Use of Oil.

The **step bearing** should be **oiled** with a small drop of the highest grade jeweler's watch oil.

Registers.

The tester should inspect the **register** very carefully, as there is always a liability of defects which may prevent its recording all of the revolutions of the moving element.

Worm or Pinion.

The **worm or pinion** on the shaft should be carefully examined to see that it meshes properly with the register wheel which it drives. A slight amount of play is necessary to prevent too much friction.

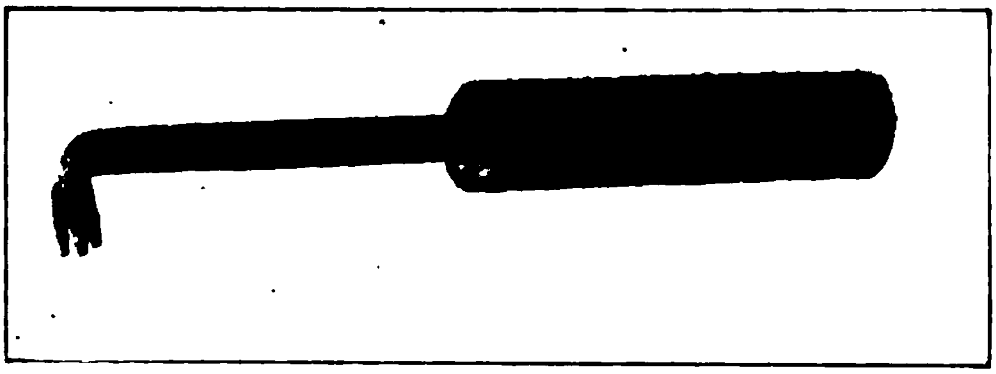


FIG. 255.—Dial Hand Tool.

Where the pinion or worm is short, or where the worm is cut concave to match the curvature of the worm wheel, the height of the moving element should be set so that the center of the pinion or worm is on a level with that of the register wheel which it engages.

For cleaning the pinion or worm, a small stiff brush or a sharpened piece of soft wood may be used.

Gears and Dial Hands.

All the **gears and dial hands** on the register should be gone over, pressing each back and forth with the fingers to insure that each wheel meshes with its neighbor and that the hands, pinions and wheels are tight on their shafts. Misplaced hands should be corrected, not by twisting them to place, but by pulling them off with a suitable tool, Fig. 255, and resetting firmly to the proper position.

The register should be removed from the meter and spun around to make sure that it runs freely. When replaced it should be carefully reset to the original reading.

It is the usual practice to reset the register to zero in the laboratory, and where this is the practice it should be done by spinning the gear train instead of by resetting the hands, unless the reading is so large that this would take too much time, in which case the hand of the last dial only may be reset.

Cyclometer Registers.

In some **cyclometer registers** the amount of friction is variable, being greatest when several of the numbers on the dial are being shifted at the same time. Meters having such registers should be adjusted to be correct when the friction is least.

Other Causes of Friction.

Other causes of friction might be dirt between the magnets or anything coming in contact with any portion of the moving element, bent shaft, broken pivot points, top bearing stud too low, bent frames, etc. Too **loose light load adjustment** might cause meter to run too fast or too slow, principally at light load, by increasing or decreasing the friction compensating torque.

Stray Fields.

Stray fields may make a meter register either too fast or too slow, depending upon their polarity. A test for stray field in magnitude and direction may be made as follows.

Remove all the connecting wires from the meter and attach a galvanometer to the brush terminals. Then rapidly twirl the armature, which will cause a deflection of the galvanometer, if the stray field is present. To measure the stray field pass enough current through the current coils in the proper direction to cause the galvanometer to remain at zero when the armature is twirled. By measuring this current with an ammeter it gives the effect produced by the stray field.

Creeping.

Creeping is a slow rotation of the moving element when there is no load whatever in the consumer's circuit. It may occur either backward or forward, but usually in the latter direction. When the load is removed, a meter will sometimes rotate for a part of a revolution before coming to rest. All observations of creeping should therefore be based upon at least one complete revolution.

Although only an unusually rapid rate of creeping will result in an appreciable registration, yet as a matter of principle no meter in service should be allowed to remain creeping.

Causes of Creeping.

The causes of creeping are as follows:

(a) Incorrect compensation for friction.

(b) Vibration which reduces the friction and allows the compensating torque to rotate the moving element.

(c) Stray fields.

(d) Too high voltage.

(e) The potential circuit being connected on the load side of the meter when the friction compensation has been adjusted with the potential circuit connected on the service side.

(f) Short circuits in current coils of induction meters.

Leakage or grounding in the consumer's circuit may cause a rotation of the moving element which may be mistaken for creeping. The observations of creeping should therefore be made with the load wires removed from the meter. To detect leakage in the consumer's lines, note may also be made whether the meter runs with this wire connected.

Prevention of Creeping.

If the meter still creeps after it has been properly adjusted, it is necessary to make use of some special anti-creep device.

The most common **method of preventing creep** is to force over the edge of the disk a small U-shaped piece of iron wire or "clip" which is attracted by the drag magnets and tends to remain stationary in the position where it is closest to one of the poles. When the meter is rotating under load, the accelerating force as the wire approaches the magnet is equal to the retarding force as it leaves the magnet, so that the effect on the accuracy of the meter is small. In placing the clip, care should be taken not to injure the disk and to locate it so that it is not likely to hit the magnets.

In some meters a piece of iron wire is attached to the disk near the shaft, giving the same effect.

The effect of the clip is varied by changing its length and position. To make this adjustment properly requires good judgment. The tester must take account of the character of the installation and of the location, and set the clip so that it will not prevent the meter starting on a light load, and yet so that the meter is not likely to creep under conditions which may exist at some time later. The starting current should be determined after adjusting the clip.

In some induction meters, creeping is prevented by two holes cut in the disk on opposite sides of the shaft. When either hole is near

the pole of the potential coil, forces set up by the alternating field tend to hold the disk in this position.

If a short circuit is present in the current coils it will probably be found impossible to stop creeping. The creeping is caused by currents being induced in the current coils by the potential magnetic flux. The coils should either be removed and the convolutions properly insulated, or replaced by new ones.

Starting Current.

The **starting current** is the current required at normal voltage to start the moving element from rest and rotate it through one or more revolutions. In practice, the starting current is ordinarily determined, roughly, in terms of the watt rating of the test lamps.

Where the meter has an anti-creeping clip, the starting current should be taken when the clip is nearest the magnet pole.

Three-wire Watt-hour Meters.

The following methods of connection may be used in **testing three-wire watt-hour meters:**

I. The normal service connections may be used, the load being connected between the outer wires on the house side of the meter (Figs. 277, 278, 279, 282 and 283).

II. The current coils may be connected in series and the meter tested as a two-wire meter, connecting the load on one side of the three-wire circuit (Figs. 280, 281, 284, 285 and 286).

III. The current coils may be connected in series to an independent testing circuit, such as a storage battery or a step-down transformer (Fig. 287).

Testing with the normal connection of the current coils requires a load box adapted to the full voltage between the outer wires. Tests are usually made by connecting the current coils in series.

The connection of the current coils in series is made by removing one service connection and both house connections from the meter (Figs. 280 and 284), connecting the two house terminals of the meter together. The load box is then connected from the disconnected service terminal of the meter to the neutral (Figs. 281, 285 and 286). In the case of loading by means of a transformer or storage battery, the load circuit is connected to the two service terminals of the meter (Fig. 287).

A three-wire meter whose voltage circuit is connected between the neutral and one outer wires measures the energy, based on an assumption of balanced voltages.

In testing a meter of the above type with the normal service connections, the voltmeter or voltage circuit of the standard is

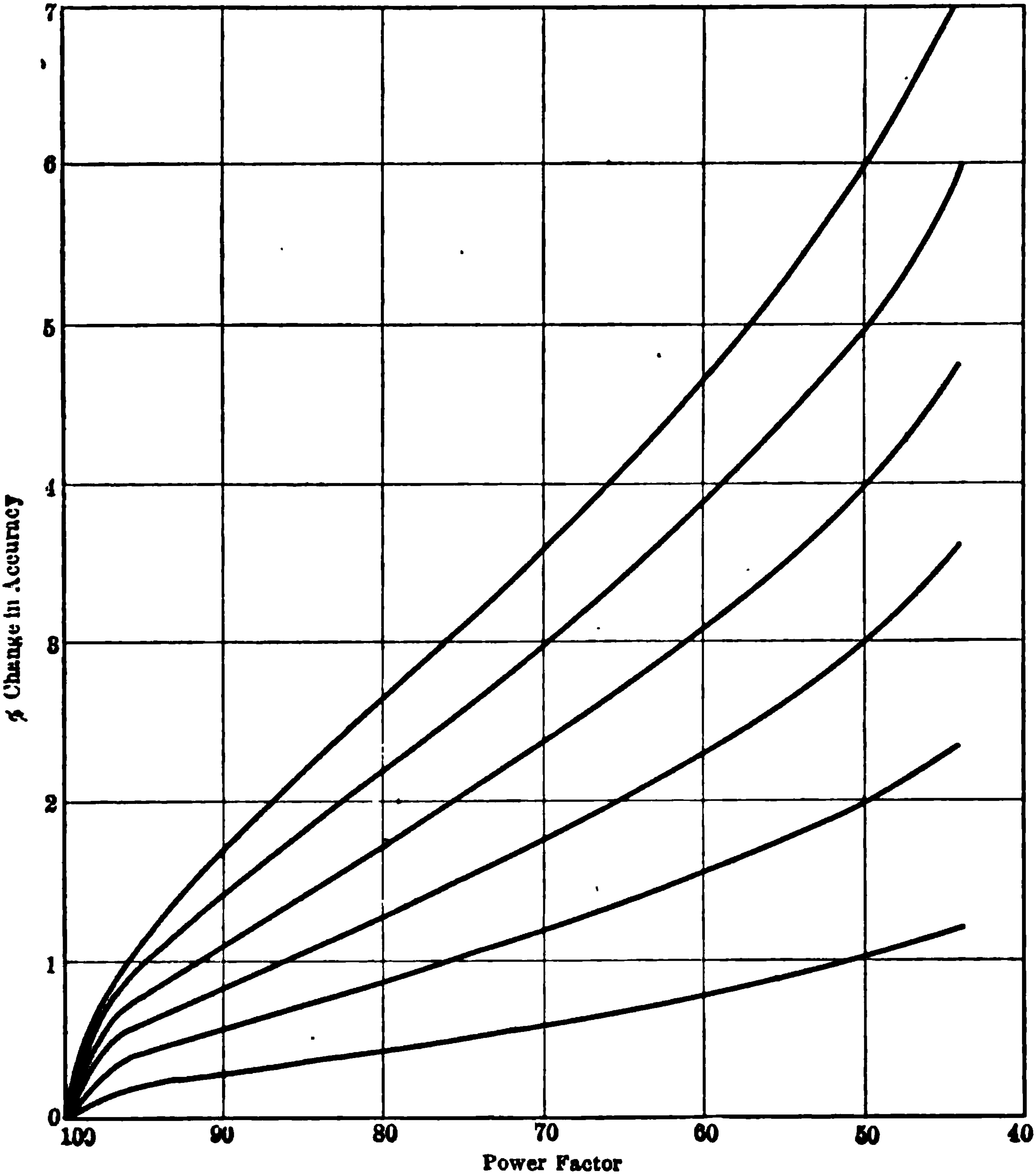


FIG. 256.

connected in parallel with the voltage circuit of the meter, so that the standard indicates the true amount of energy affecting the meter, instead of the total energy in the three-wire circuit. Therefore, the

watt-second constant as a three-wire meter is halved to obtain the test constant.

In testing a meter of the above type on a two-wire circuit, with the current coils in series, the true amount of energy affecting the meter will, as in the above case, be the same as that indicated by the standards, and the assigned watt-second constant should therefore also be halved in this case.

A three-wire meter whose voltage circuit is connected between the outer wires measures the total energy directly (assuming the voltages to be balanced), and hence the testing constant and watt-second constant are equal.

Alternating Current Watt-hour Meters.

Alternating current watt-hour meters may be tested on the consumer's premises with an indicating wattmeter and stop watch; with rotating standards, or with calibrated resistance, voltmeter and stop watch.

Ammeters and voltmeters should not be used because of the liability of error due to power-factors below unity.

The order of procedure for **induction meters** is the same as for commutator types of meters, omiting items 4 and 8.

The **adjustments** are to be made **for full load, and light load** and also the **lag adjustment.** The latter is ordinarily used only in the laboratory tests, and it is not the general practice to make this adjustment in service. The explanation of **full and light load adjustments** given under the test of continuous current watt-hour meters applies to induction meters.

The **lag adjustment** alters the speed on the low power-factors. Fig. 256 gives theoretical curves showing how changing the accuracy 1 per cent, 2 per cent, 3 per cent, etc., at a power-factor of .50 will affect the accuracy at the other power-factors. Due to the characteristics of particular types, some watt-hour meters may deviate from these curves. In some meters, changing the lag adjustment affects the accuracy at unity power-factor, and the curves are based upon the assumption that when the lag adjustment is shifted the full load adjustment is also shifted to compensate for this effect.

Service watt-hour meters may be loaded for test by using special rheostats, transformers, or water rheostats. (See Chapter IX.) The consumer's load may also be used, or used in connection with some of the above methods.

If a meter is found inaccurate, look for and correct the following troubles before making any adjustments:

Induction Type Meters

Meters found	Look for
Slow. Full load and light load	Short circuit in current, or potential coils; loose magnets.
Slow. Principally at light load	Defective bearing; other excessive friction; loose light load adjustment.
Fast. Full load and light load	Weakened or loose magnets; short circuit in series reactance of potential coil.
Fast. Principally at light load	Loose, or defective, light load adjustment; vibration; short circuit in current coils.

Causes of Inaccuracy.

A **short circuit in the current coils** will cut out some of the effective turns, and consequently will lower the torque of the watt-hour meter and hence its speed at or near full load. Induction meters will, however, generally creep when some of the turns of the current coils are short circuited and often will be fast on light load and slow on full load. Generally the meters with this defect should be returned to the meter shop for new current coil.

A **short circuit in the potential coils** will change the torque of the watt-hour meter; hence its speed. A meter with this condition existing, will be found out of lag and should be sent to the meter shop for repairs.

The same remarks regarding **loose magnets** as were made for continuous current watt-hour meters apply here.

A **defective bearing** will have the same effect as on continuous current watt-hour meters, with the following addition:

Occasionally an induction watt-hour meter is found in which the **shaft rattles in the top bearing,** due to vibration set up by the alternating fields. This causes a certain amount of wear, but the chief reason for its elimination is that in some locations the hum may be annoying. Various styles of top bearings have been devised to eliminate the difficulty, and it may be gotten rid of by changing the bearing or replacing the meter. Sometimes a change in the adjustment of the bearings so as to alter slightly the vibrating length of the shaft will start the humming.

A **loose light load adjustment** should be treated the same as for continuous current watt-hour meters.

Weakened magnets should also receive the same treatment, as for continuous current watt-hour meters. However, with exception of some polyphase watt-hour meters, comparatively few magnets are found in alternating current meters that have been weakened to such an extent that they should be changed.

Vibration, while not so damaging to alternating current watt-hour meters as to continuous current meters, still is to be avoided. It causes unnecessary wear on bearings, especially the step bearing, and also may cause the meter to creep or be fast on light load.

A **short circuit in the series reactance** of the potential circuit will allow a larger current to pass through this circuit than is normal, causing too high torque and consequently too high speed. The meter will be out of lag and is quite liable to be noisy. The remedy is to send it to the meter shop for repairs and recalibration.

If a watt-hour meter operates exclusively on an inductive load, it may be found convenient, and advisable, to make a test using consumer's load. This test is not difficult to make where a rotating standard is used.

Polyphase Watt-hour Meters.

Polyphase watt-hour meters which are acceptable under the single-phase specifications given in Section IV-D, Clause 2, and Section IV-C, Clauses 1 to 14, inclusive, of the Code for Electricity Meters, may in service be tested on a polyphase load, or by either of the following methods:

I. Connecting the voltage coils in parallel and the current coils in series and testing as a single-phase meter.

II. Connecting the voltage coils in parallel and loading each current coil separately, the percentage of load then referring to the percentage of the total watt capacity of the meter, provided that no test shall be made at a load exceeding 100 per cent of the current capacity of one element.

Meters which do not conform to the requirements of the above Clause 2, Section IV-D, but which are acceptable as having passed the requirements of Clauses 1 to 14, inclusive, Section IV-C, of the Code for Electricity Meters, must be tested upon a polyphase circuit. Either of the methods given below may be used. The connections should be the same as to relative polarity of the elements and relative phase relations, as in service.

I. The watt-hour meters may be tested on an approximately balanced polyphase load with standards in each phase, or, in the case

of a three-phase circuit on a balanced "V" connected load. (See Fig. 289.)

II. The tests may be made on each element separately, the potential circuits of the meter being connected to a polyphase circuit in the same manner as in service, the various percentages of load then referring to the percentage of the total watt capacity of the meter, provided that no test shall be made at a load exceeding 100 per cent of the current capacity of one element.

In testing polyphase watt-hour meters, with current in only one phase, the rotating standards are used in the same manner as in single-phase tests.

The working standards used in polyphase tests may be: (a) single-phase indicating wattmeters, or rotating standards (Fig. 289); (b) a polyphase indicating wattmeter, or rotating standard.

Where two single-phase rotating standards are employed, they may be started by operating the two controlling switches together, or by using a double controlling switch.

When polyphase indicating wattmeters, or rotating standards, are used, they must be properly calibrated for polyphase interference conditions in the various coils and circuits, in the manner set forth elsewhere.

Alternating current induction watt-hour meters are accurate only at the frequency for which they are built, therefore, if any material **change in the frequency** is made on a system, say from 133 to 60 cycles, it will be necessary to give consideration to all the induction watt-hour meters and make certain changes in them, if accurate registration is desired. Practically, the error is negligible for small variations in frequency, but a large change will make large errors, which will be greater on inductive than on non-inductive loads. Commutator watt-hour meters will be affected very slightly by the change. There are some types of induction watt-hour meters which are double lagged, or otherwise adaptable to two frequencies, such as 133 and 60 cycles. In these meters it is necessary to make certain small changes such as soldering, or changing a small connection and then recalibrating the watt-hour meter at unity power-factor. As the above mentioned meters have been lagged at two frequencies at the factory, it is quite probable that, after making the required changes, the meter will be accurate on inductive loads. However, it is recommended when a material change in frequency is made that the watt-hour meters always be brought to the meter shop, tested on low power-factor and relagged if found necessary. Watt-hour meters that are not double lagged will probably require new potential circuits or parts pertaining thereto, as well as

recalibration. It is better that this work be done in the meter shop. Where such a change in frequency is made, it would, in all cases, be advisable to consult the respective manufacturers about all the watt-hour meters which a company may have on its system.

Methods of Determining Correct Connections of Polyphase Watt-hour Meters.

Because of the fact that quite often the low-tension leads from the instrument transformers of a polyphase watt-hour meter are so run that difficulty is experienced in tracing them, and because the correctness of the connections cannot be directly checked by observing the direction of rotation of the disk, a demand has been felt for a simple, practical check, to satisfy which the following is suggested.

In **checking connections on three-phase watt-hour meters,** the following points should be clearly fixed in mind:

(1) Either element, or both elements, of a three-phase watt-hour meter should cause rotation in a positive direction (the normal direction indicated on the meter) when the power-factor of the load, to measure which the watt-hour meter is connected, is above 50 per cent.

(2) One of the two elements of a three-phase watt-hour meter will cause negative direction of rotation (although both elements acting simultaneously will still cause positive rotation, when the power-factor of the load to measure which the watt-hour meter is connected is below 50 per cent. At exactly 50 per cent power-factor one element will cease to cause rotation of the disk. In practice, with the power-factor hovering about 50 per cent, the disk will be caused, by one element acting alone, viz.: the low reading element, to creep in one direction, next to stop, then to creep in the opposite direction, and so on, as the power-factor passes from a value less than 50 per cent, through and to a value of greater than 50 per cent and vice versa.

(3) With a reversal of potential leads will occur a reversal of the direction of rotation of the disk, when acted upon alone by the element of the meter to which the potential lead was reversed.

From the above, it will be noticed that a wrong connection of the potential leads, which is in the nature of a reversal, can be detected by noting the direction of rotation of the disk when acted upon by each element separately. Also, in order to know what the direction of rotation of the disk should be, the power-factor must be known In other words, in order to prove that a condition of "reversed potential lead" does not exist, it is necessary to have within our grasp

means of intentionally varying the power-factor from a value greater than, to a value less than, 50 per cent.

Since every consumer requiring a three-phase meter has at least one three-phase motor, the following steps may be taken to prove that a condition of reversed potential lead does not exist:

(a) With but one induction motor running, remove its load, by throwing belt or otherwise, as the case may require. The motor is then running idle, and, being of an induction type, the power-factor of the load will be below 50 per cent, and, if properly connected, the direction of rotation of the disk of the meter, due to the action of one of the elements alone, should be negative. Disconnect one of the potential leads leading to one of the elements of the meter. The direction of rotation of the disk having been noted, replace the potential lead and disconnect lead from other element, again noting direction of rotation of disk.

As stated in (2), above, the direction of rotation of the disk with power-factor below 50 per cent should, with one of the elements acting alone, be negative; with the other acting alone, positive, and with both acting together, positive. We have, however, assumed that the power-factor resulting from the use of an induction motor alone, and without load, is below 50 per cent. While this is a fair assumption, the action of the meter will prove that the power-factor has passed through 50 per cent, by the fact that the disk when acted upon by one of the elements alone, viz.: the low-reading side, will change the direction of rotation at the time of again loading the motor.

(b) Load the motor either by again placing belt or otherwise. Disconnect first one potential lead and then the other, as before, and note direction of rotation of disk. The power-factor now being brought to a higher value, and above 50 per cent, rotation of disk due to each element of meter, and to both elements, should be positive.

Since by loading the induction motor we positively know that we have bettered the power-factor, and since the direction of rotation of the disk due to the action of one of the elements alone has been reversed, thereby proving that the power-factor has been passed through 50 per cent, we must have raised the power-factor from a value less than, to a value greater than, 50 per cent, and, therefore, the actions of the meter in case (a) should satisfy the conditions of power-factor below 50 per cent, and in case (b) should satisfy conditions of power-factor above 50 per cent.

It may accidentally happen that the voltage transformer, which

should have been connected to the same element of the meter as one of the current transformers, is, incorrectly, connected to that element of the meter to which the other current transformer is connected, or vice versa.

This condition is, in the case of exposed wiring, easily detected, but in case the secondary wires from the potential and current transformers are run in conduit, the following simple method of check may be used:

First select either current transformer, and then the voltage transformer, the primary leads of which are connected to the same phase as the selected current transformer. This is readily done, as the primary wiring on the current and potential transformers is almost invariably exposed. Disconnect one of the secondary leads of the voltage transformer. Short circuit the current transformer and open the lead, beyond the short circuit, going to the meter. If the meter has been incorrectly connected, as described above, it will stop at once.

Because, by the above change, instead of disconnecting the voltage and current transformers supplying the same element of the meter, in which case the meter disk would have continued to rotate, and which would have been the case were the meter properly connected, one current transformer has been disconnected from one element of the meter, and the voltage transformer disconnected from the other element, thereby stopping both elements and consequently the meter.

In checking switchboard instruments in a central station, use is generally made of the fact that during the evening, at least, the power-factor on the plant is invariably above 50 per cent. Use may also be made of the characteristics of the over-excited synchronous motor; also of the fact that constant current transformers, such as are used in connection with the series alternating, or magnetite, system of street lighting, have a power-factor below 50 per cent when operating on short circuits. For instance, in a plant with auxiliary bus-bars, a generator whose watt-hour meter is to be checked may be connected to these buses, to which also the lighting constant current transformers may be connected. The direction of rotation of the meter disk being noted with and without load on the constant current transformers, will, if meter is properly connected, indicate conditions of power-factor above, and below, 50 per cent.

Mr. B. Frankenfield's demonstration of the two watt-hour meter method of measuring power in a three-phase circuit already cited in Chapter IV, may be helpfully applied in connection with these oblems.

The following method has also been suggested and found useful for determining the correct connections of a polyphase watt-hour meter in a three-phase circuit.

The watt-hour meter should be so connected that when the power-factor is less than 100 per cent, and over 50 per cent, it will rotate forward with either element cut out, but the speed will be less with one element than with the other. When the power-factor is less than 50 per cent and more than zero, rotation will be forward, with one element cut out, and backward, at a lower speed, with the other element cut out. The resultant rotation will, however, be forward.

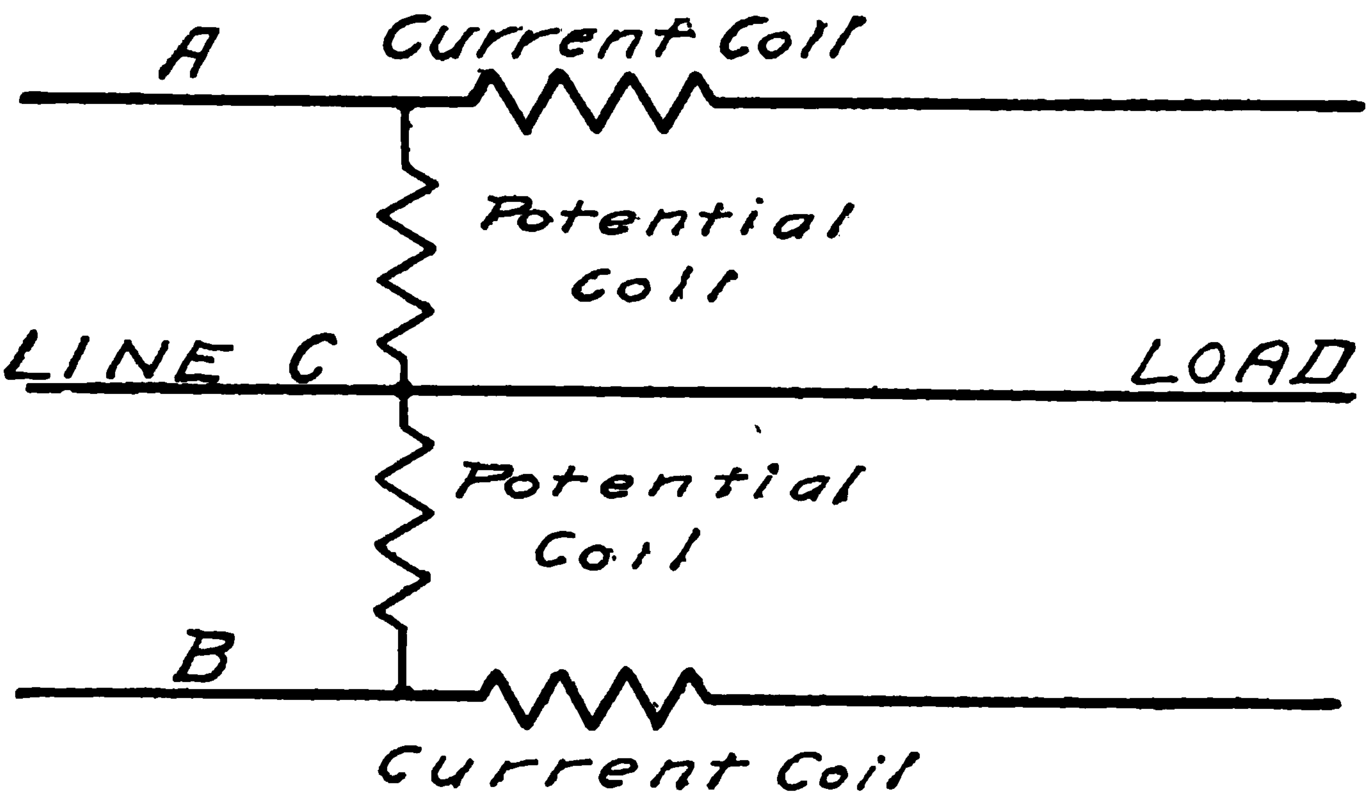


FIG. 257.—Connections without Voltage or Current Transformers.

In cases where it is not positively known that the power-factor is above 50 per cent, the following method may be used:

First, by testing with an incandescent lamp, or a voltmeter, see that the voltage leads *A, B,* and *C* have equal voltages between them.

Second, connect these leads to the potential circuit of the watt-hour meter, as shown in Figs. 257 and 258.

Third, connect the second transformer in line *A* to the element whose potential coil is connected to *AC* and the current transformer of line *B* to the element whose potential circuit is connected to *BC*. Fig. 259 is a vector diagram showing the phase relations with these connections. In this diagram *AC* represents the voltage on the element connected at *A, BC* the voltage on the element connected at *B, OA* the current in the element connected at *A,* and *OB* the current in the element connected at *B.*

Fourth, disconnect the current coil *B*, and note the speed of the meter with element *A* alone. Then change the voltage connections of element *A* from *AC* to *AB*. If the power-factor is 100 per cent, the meter will run at the same speed as before. If the power-factor is less than 100 per cent and greater than 50 per cent, the speed of the meter will be different but will be in the same direction in each case. If the power-factor is less than 50 per cent, the meter will run in opposite directions with the two connections.

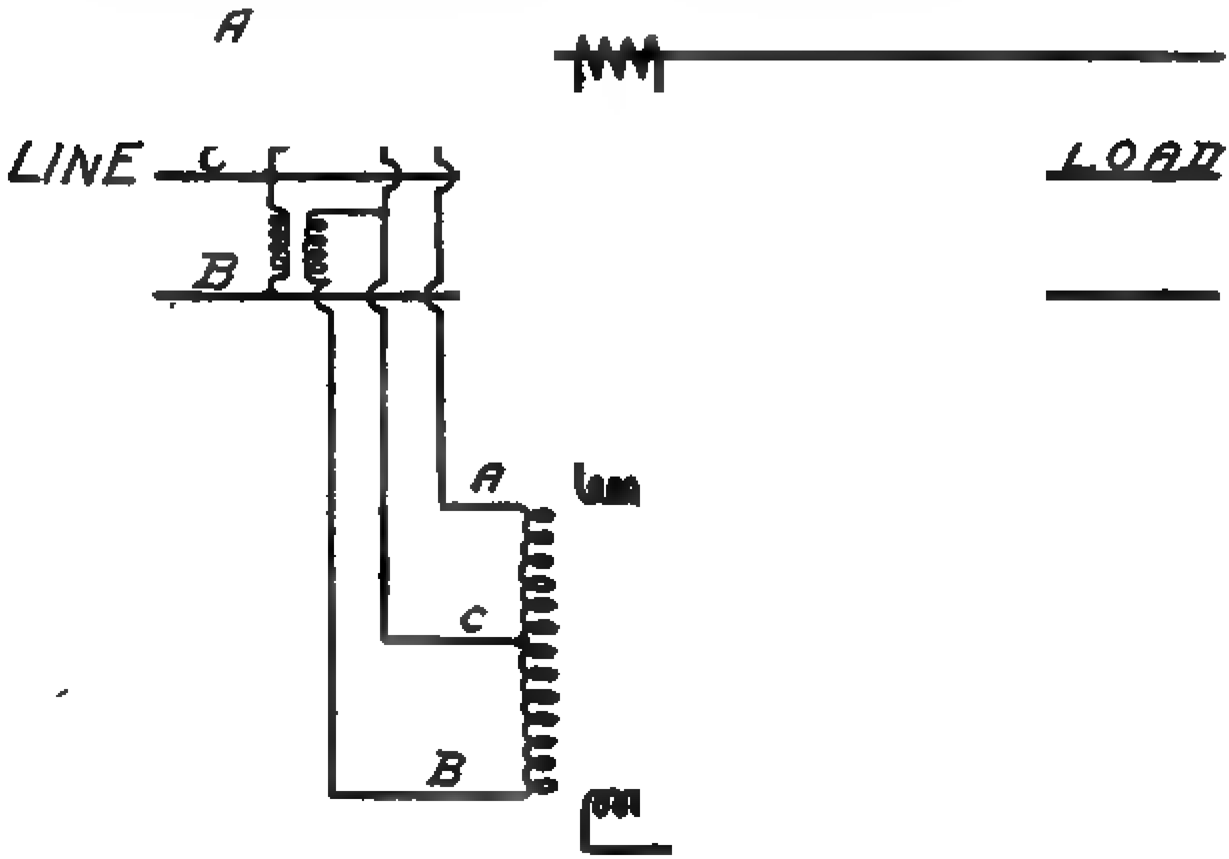


FIG. 258.—Connections with Voltage and Current Transformers.

Fifth, the same test may be performed on element *B* by changing the connections of its potential coil from *BC* to *BA*.

Sixth, if it is found from the above tests that the power-factor is greater than 50 per cent, connect the current coils so that each element tends to run forward. If the power-factor is less than 50 per cent, connect the current coil of the slower element so that it tends to run backward and the current coils of the faster element so that it tends to run forward.

If the changes are made while the circuits are alive, care should be taken never to open the secondary circuit of a current transformer. Serious personal injury may result or the magnetic state of the

iron may be altered sufficiently to materially change the ratio. These dangers may be avoided by always short circuiting the current trans-secondary before opening the meter circuit.

Where the connections cannot be easily traced, ringing out by the ordinary magneto method is the most reliable means of identifying the various circuits.

Watt-hour meters, installed on consumers' premises, with voltage

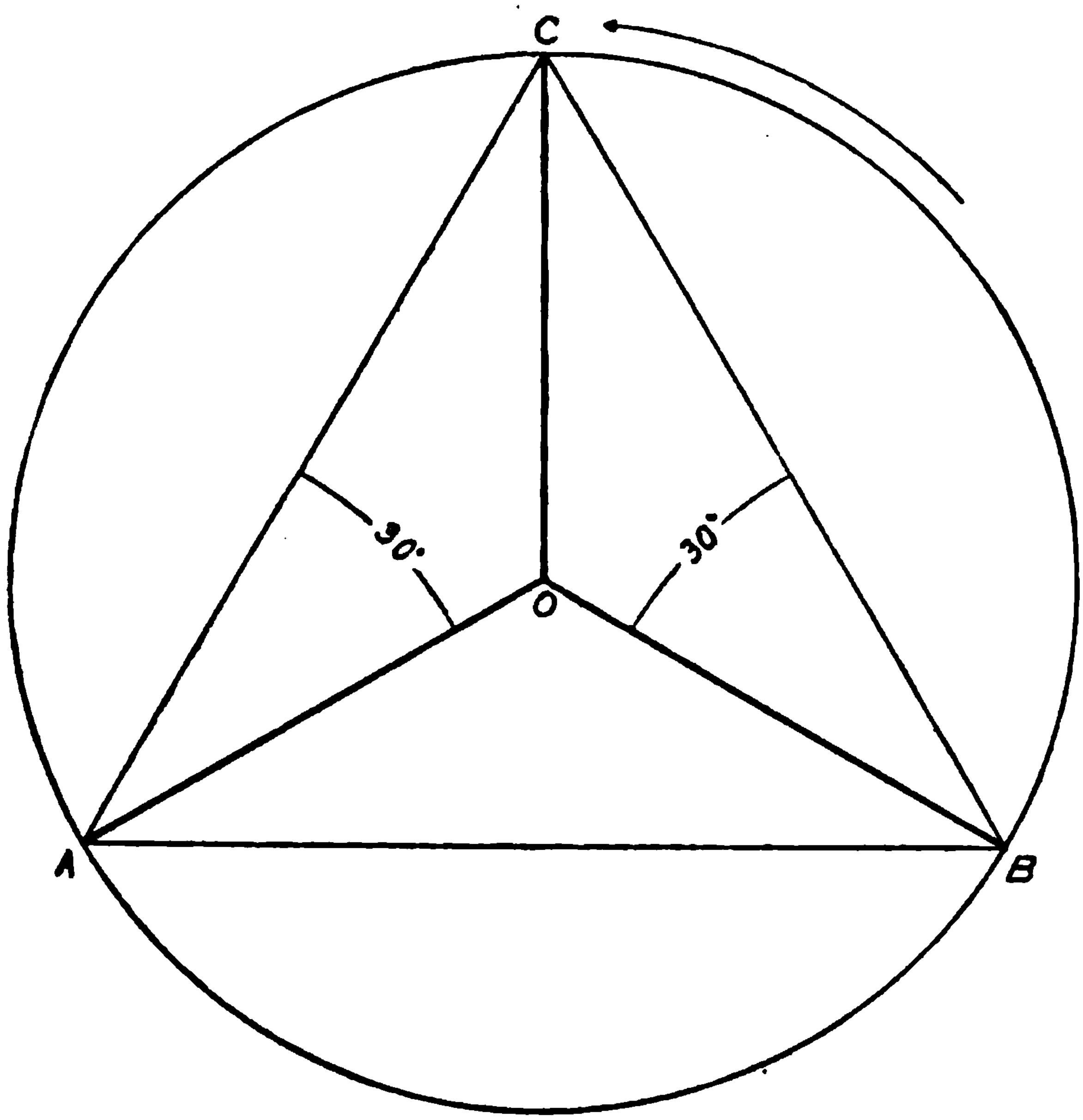


FIG. 259.—Vector Diagram of Phase Relations.

and current transformers, must be correctly calibrated with respect to the energy in the high-tension circuit.

A correct calibration is obtained directly by connecting the working standards in the high-tension circuits of the transformers (Figs. 292 and 293). In such tests the impedance in the low-tension circuit of the transformers should be the same as in service. This procedure should be followed where feasible.

In the case of high voltage, or heavy current lines, and also in some other cases where the character of the installation is such as to make high-tension tests difficult or impossible, recourse may be

had to low-tension tests; provided, however, that the transformer errors are determined and are taken account of in the calibration of the watt-hour meter under test. The percentage of accuracy of the watt-hour meter should be adjusted to correspond to a predetermined correction curve, which gives, with each load, the amount by which the percentage of accuracy with respect to low-tension energy, must differ from 100 per cent, in order to correct for the transformer errors. This value of watt-hour meter accuracy is hereinafter for brevity referred to as the secondary accuracy.

The **permanency of commercial transformers** is such that their ratios may be relied upon to remain unchanged for a period not greater than five years, provided that the transformers have not been subjected to overloads, high-tension short circuits, or open circuiting of the low-tension winding of the current transformer under load.

The phase displacements in the voltage and current transformers will appreciably affect the accuracy of the watt-hour meter only at low power-factors.

The effect will be equivalent to a certain error in the lag adjustment, and may be compensated by relagging the watt-hour meter with the transformer in the laboratory prior to installation. For methods of lagging the meter in the laboratory, see Chapter V.

Owing to the fact that the phase displacement of a current transformer varies with load, it is impossible to obtain a lag adjustment which is absolutely correct for all loads. Errors from this source may be minimized by the use of transformers having a small phase angle and by having the lag adjustment made in the laboratory at a load representing as nearly as possible the normal load of the circuit in which the watt-hour meter is to be used.

In high-tension tests where the voltage and current exceed the range of ordinary wattmeters and rotating standards, portable current and voltage transformers may be used in connection with low range working standards. The correction curve of the combination is obtained by testing the working standards in conjunction with the transformers, or by obtaining through the laboratory the corrections as given in Chapter V, and applying them to the correction curve of the working standard as determined without the transformers.

In testing watt-hour meters used with current transformers special methods of loading are often necessary.

Where the primary voltage is low, permitting loading the watt-hour meter and transformer together, from the primary, the current will ordinarily be so large as to preclude the use of load boxes of the ordinary capacity. Step-down transformers may be used to fur-

nish the large currents or the consumer's load may be used (Figs. 292 and 293).

In testing on low voltage circuits with working standards in the secondary, the loads may be obtained very conveniently by short circuiting the current transformer, then disconnecting the watt-hour meter from the current transformer, and loading it independently, obtaining energy from the high-tension circuit (Figs. 294, 295 and 296).

Where the primary voltage is high, the current for test may be obtained from the low-tension side of a step-down transformer supplied by the same system (Fig. 298).

If it is possible to disconnect the current transformer from the high voltage circuit, a high-tension test may be made by including the current transformer together with the working standards in the low-tension circuit of the step-down transformer, the voltage connections of the watt-hour meter remaining undisturbed.

Where no low voltage current is available, as, for example, in the case of a circuit supplying power directly to a high voltage motor, it is necessary to make the secondary test, using the consumer's load, inserting the working standards in the low-tension side, but otherwise leaving the connections the same as in service (Figs. 299, 300 and 301).

Light load tests may be made by loading the watt-hour meter from the low-tension side of the voltage transformer, if the capacity of the transformer will permit (Fig. 302).

Where secondary tests are made at a low power-factor, using the consumer's load, the watt-hour meter should be adjusted to the value of secondary accuracy corresponding to the actual power-factor. If the watt-hour meter has been previously relagged with respect to the high-tension side, this renders the meter correct at all power-factors.

For method of determining the correction curve for use with instrument transformers and watt-hour meters, see Chapter V.

CASE I.—TWO-WIRE WATT-HOUR METER WITH ONLY ONE SIDE OF CIRCUIT THROUGH THE WATT-HOUR METER.

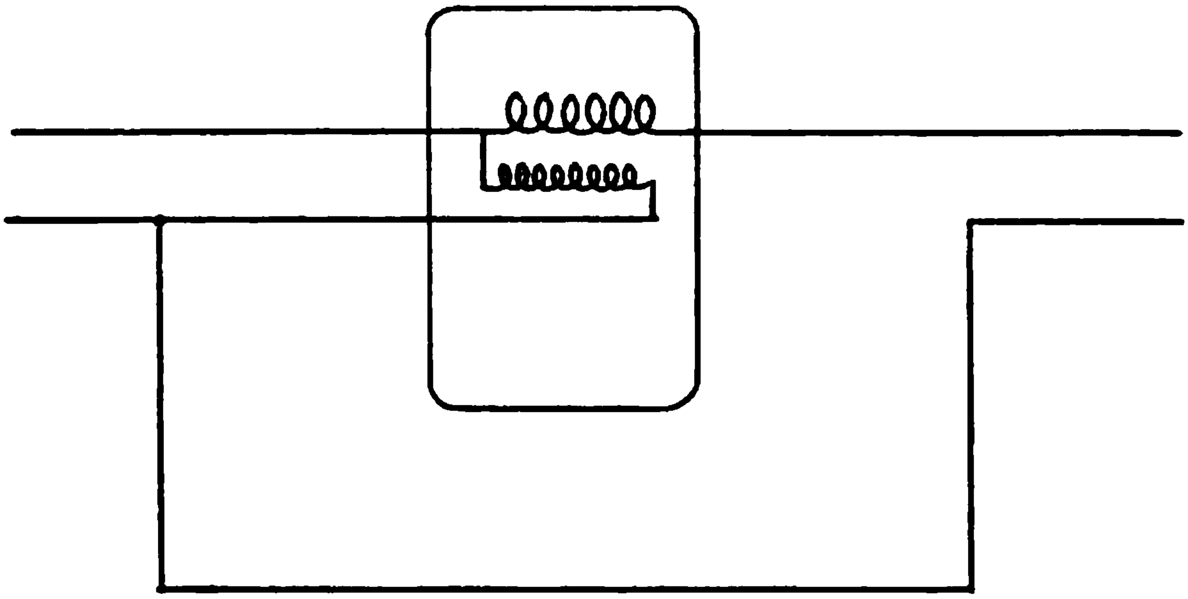


FIG. 260.—Normal Service Connections.

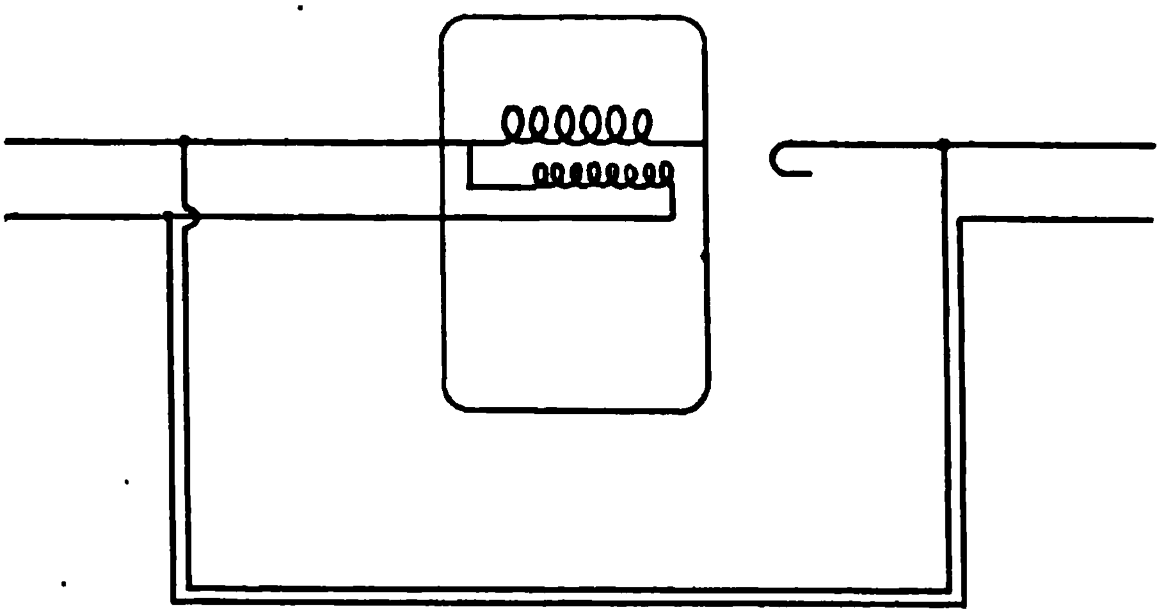


FIG. 261.—Watt-hour Meter Circuit Opened after Being Shunted.

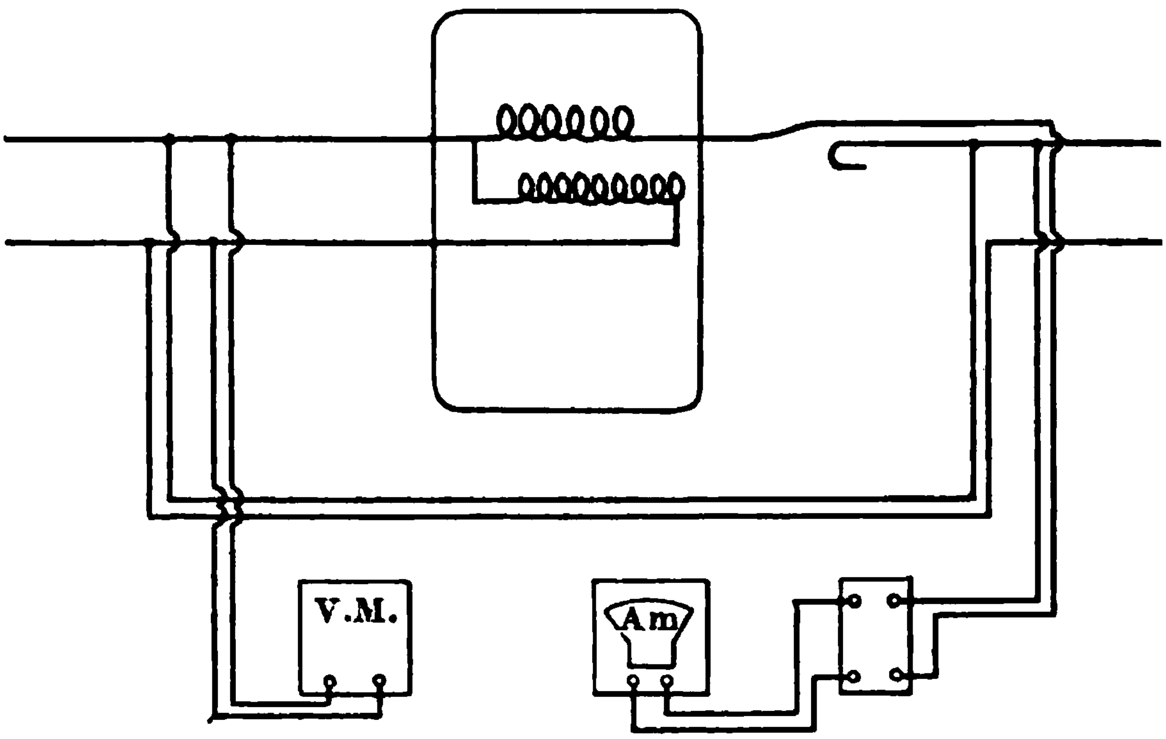


FIG. 262.—Method of Introducing Ammeter for Testing on Consumer's Load.

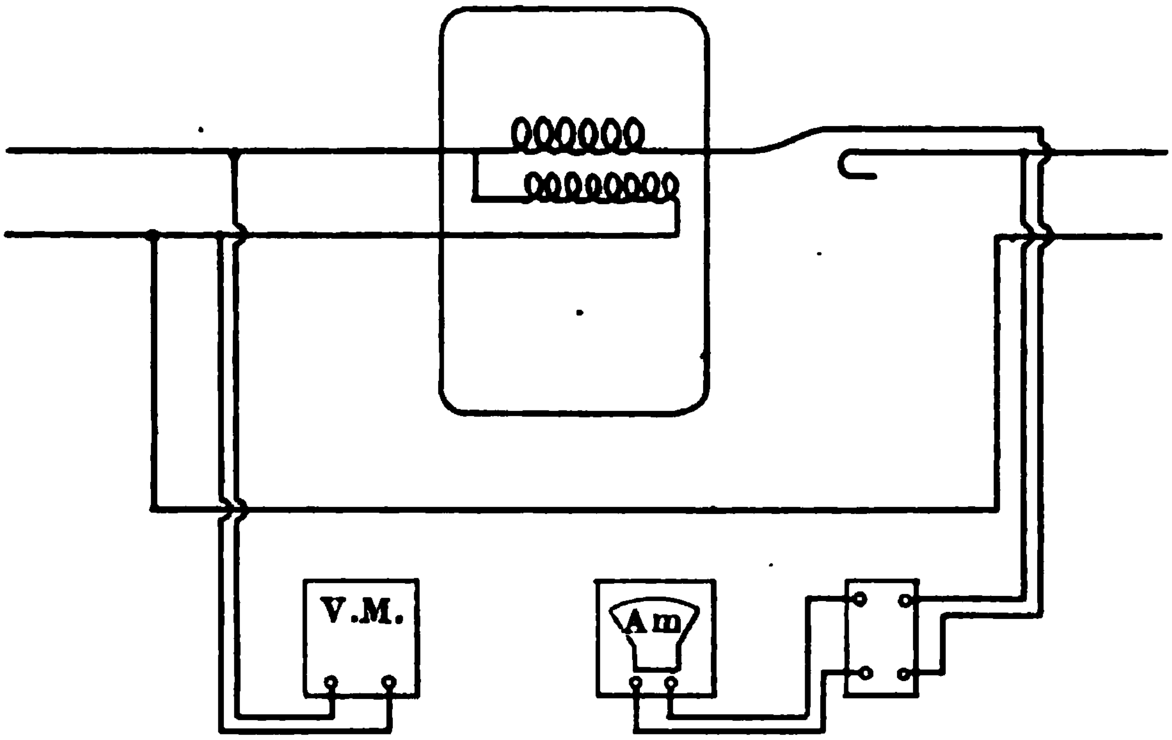


FIG. 263.—Final Connections for Testing on Consumer's Load.

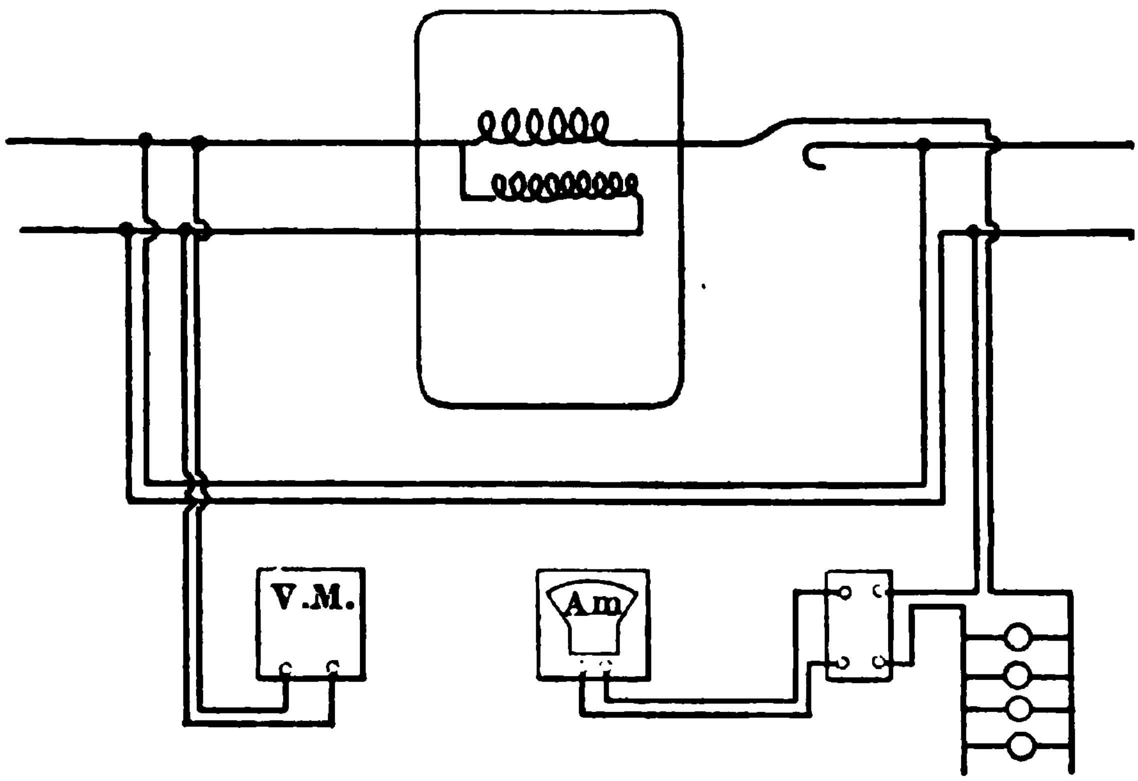


FIG. 264.—Connections for Testing with Voltmeter, Ammeter and Lamp Bank, Load Box, or Water Rheostat.

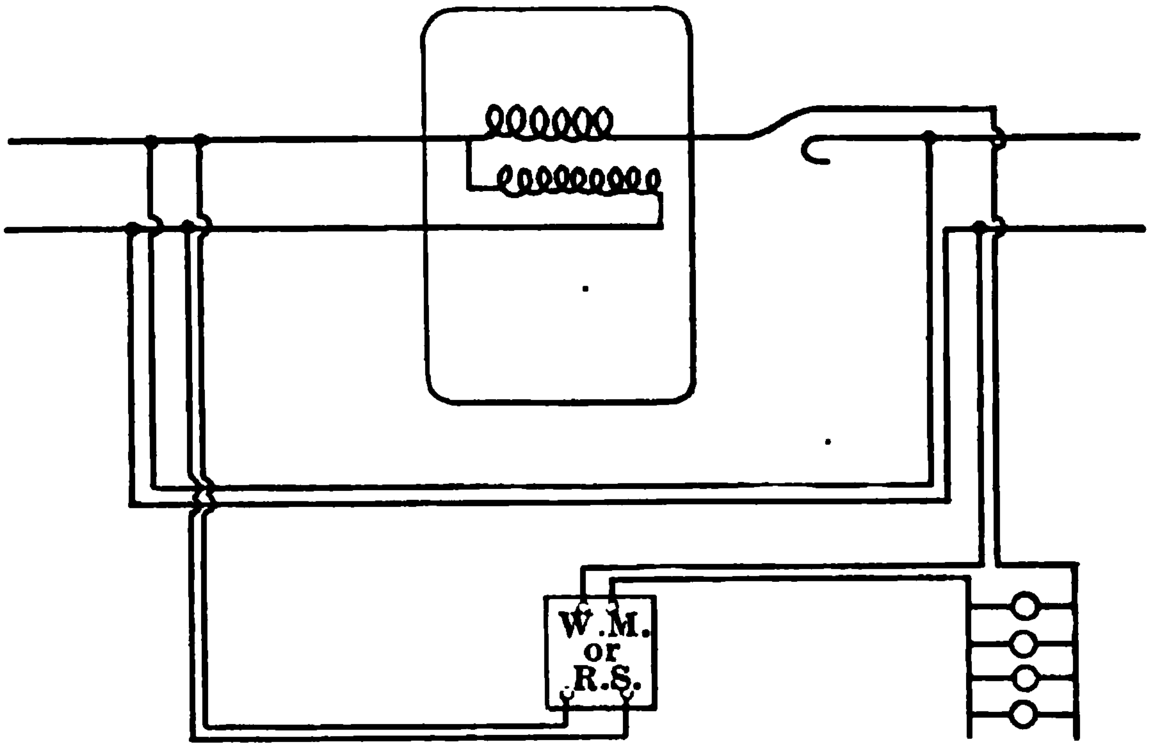


FIG. 265.—Connections for Testing with Wattmeter, or Rotating Standard and Lamp Bank, Load Box, or Water Rheostat.

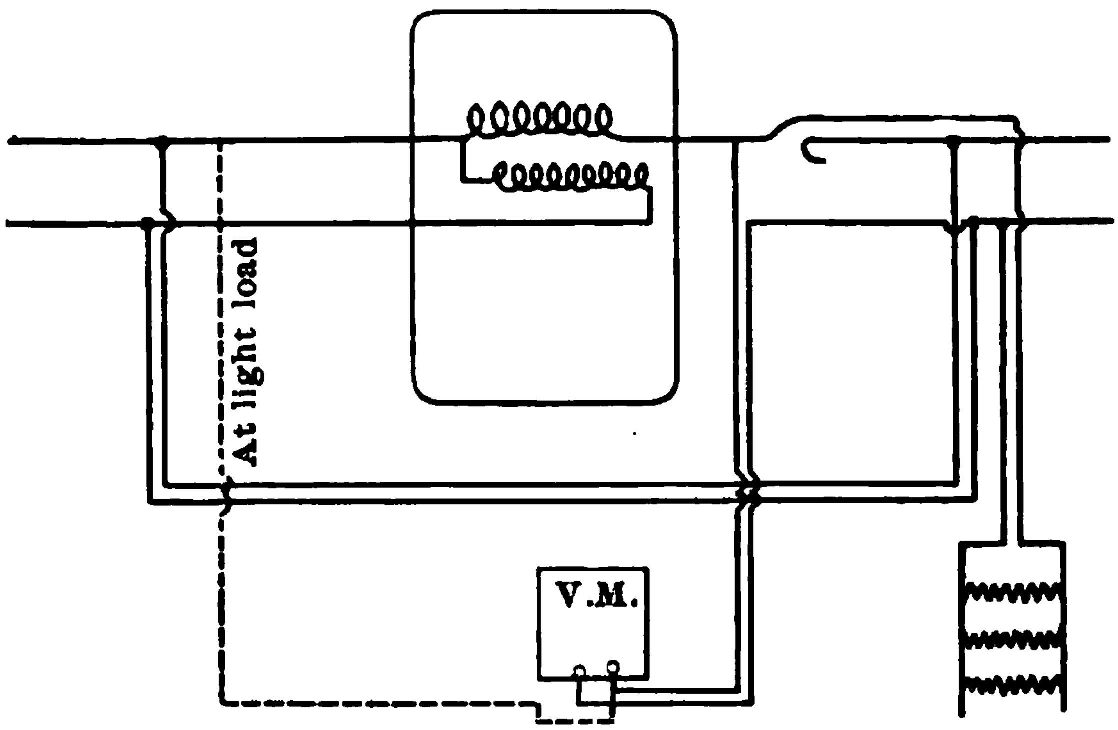


FIG. 266.—Connections for Testing with Calibrated Resistance and Voltmeter.

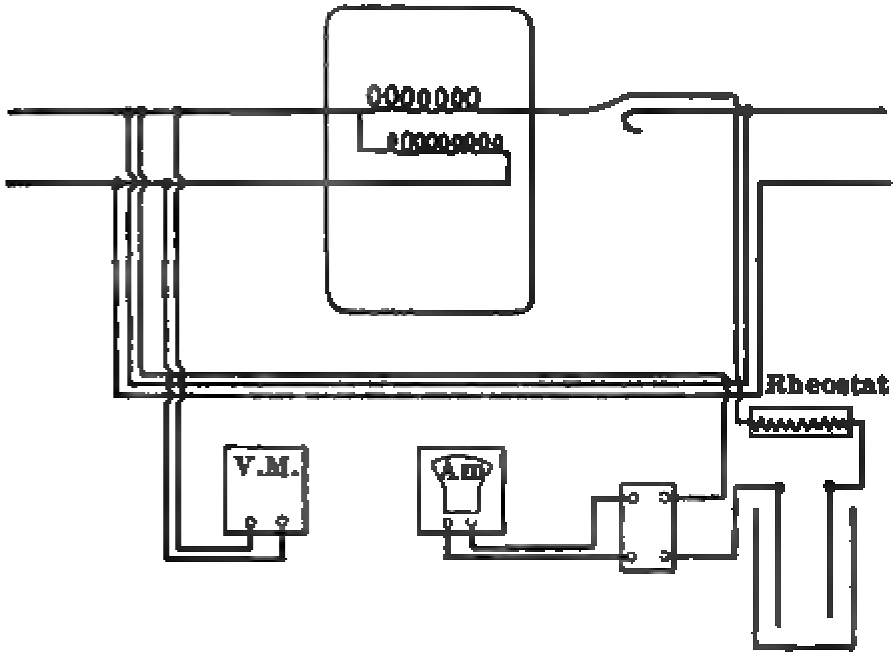


FIG. 267.—Connections for Testing with Voltmeter, Ammeter, and Storage Battery.

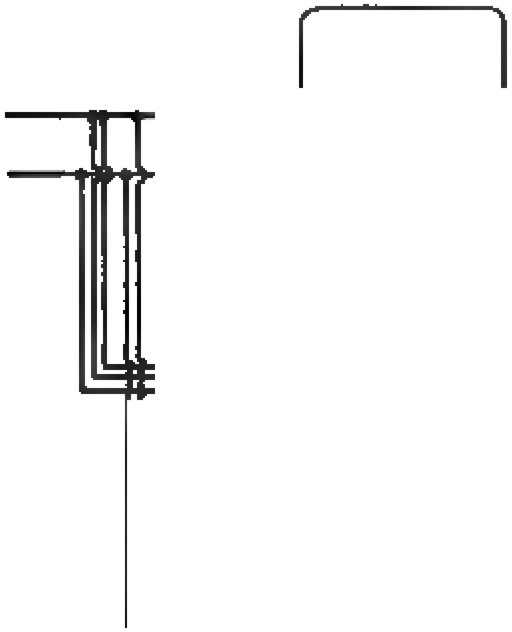


FIG. 268.—Connections for Testing on Alternating Current with Wattmeter or Rotating Standard and Transformer.

Note: When using an inverted current transformer or other transformer not adapted to the full voltage the rheostat should be inserted in the high-tension or low-current circuit.

CASE II.—Two-Wire Watt-Hour Meter With Both Sides of Circuit Passing Through the Watt-Hour Meter.

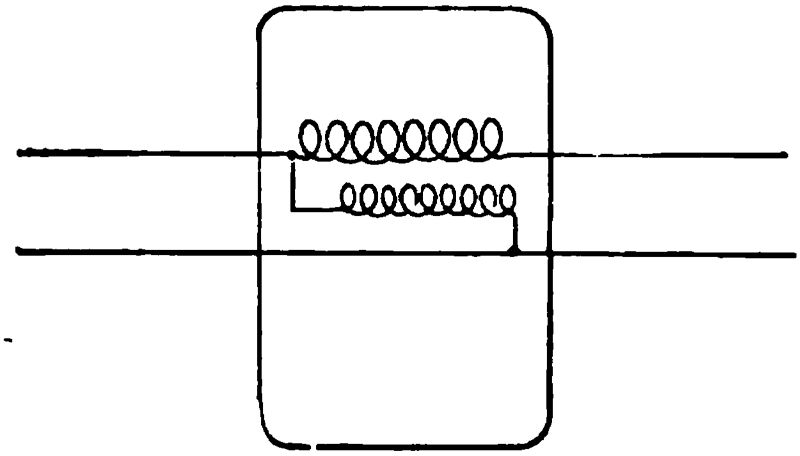


Fig. 269.—Normal Service Connections.

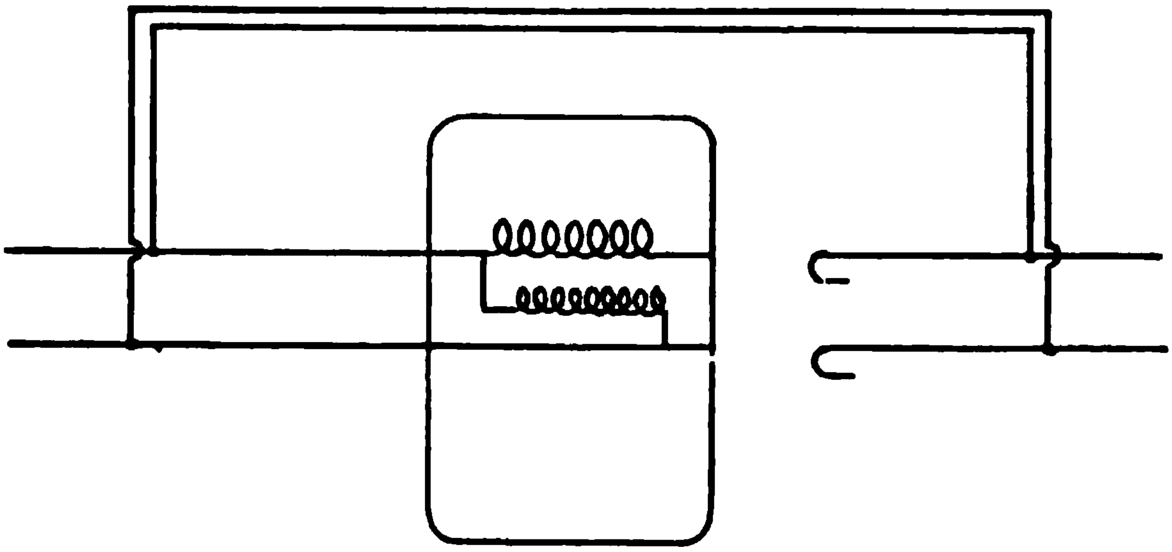


Fig. 270.—Watt-hour Meter Circuit Opened after Being Shunted.

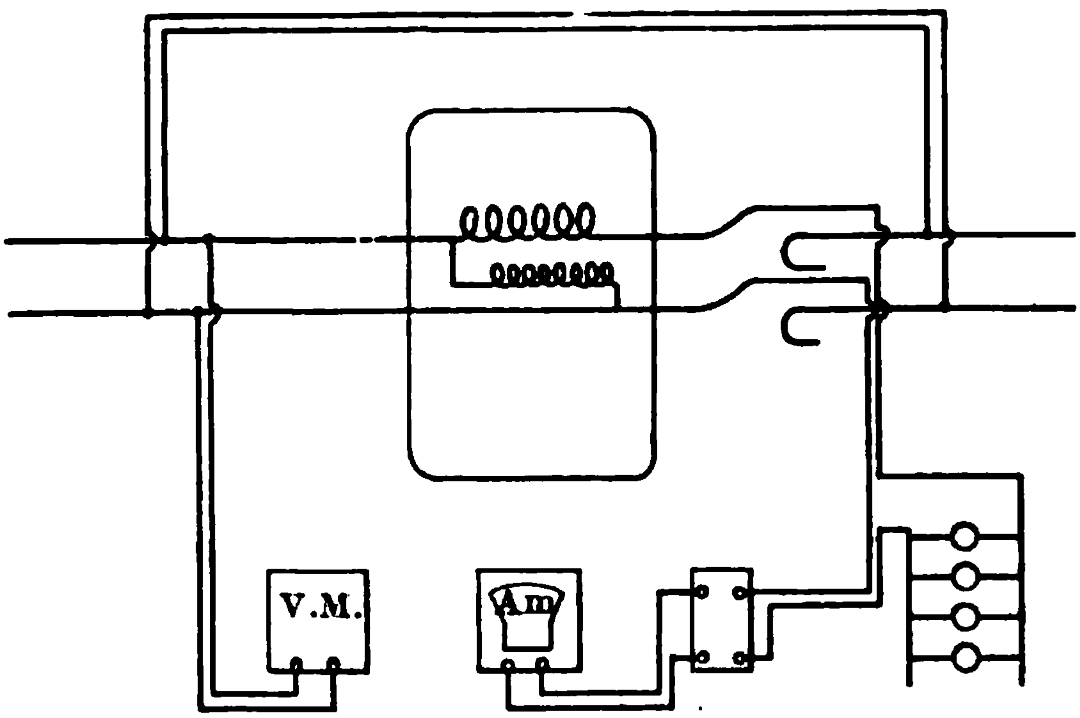


Fig. 271.—Connections for Testing with Voltmeter and Ammeter, and Lamp Banks, Load Box, or Water Rheostat.

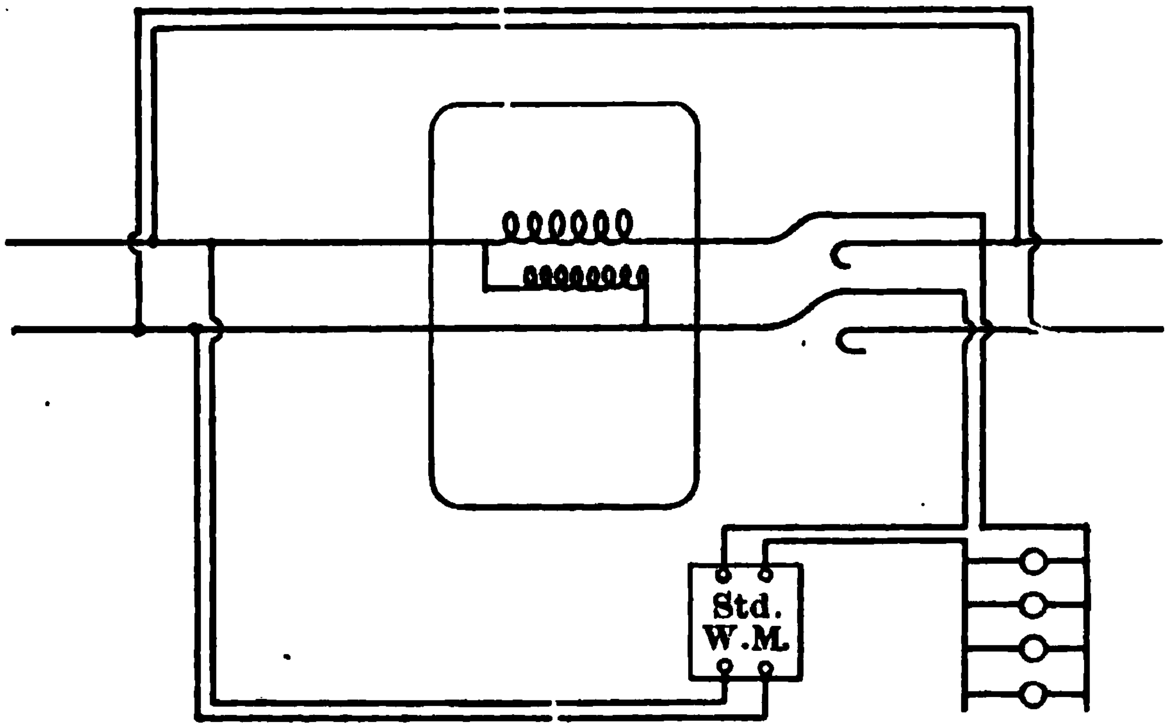


FIG. 272.—Connections for Testing with Wattmeter, or Rotating Standard and Lamp Bank, Load Box, or Water Rheostat.

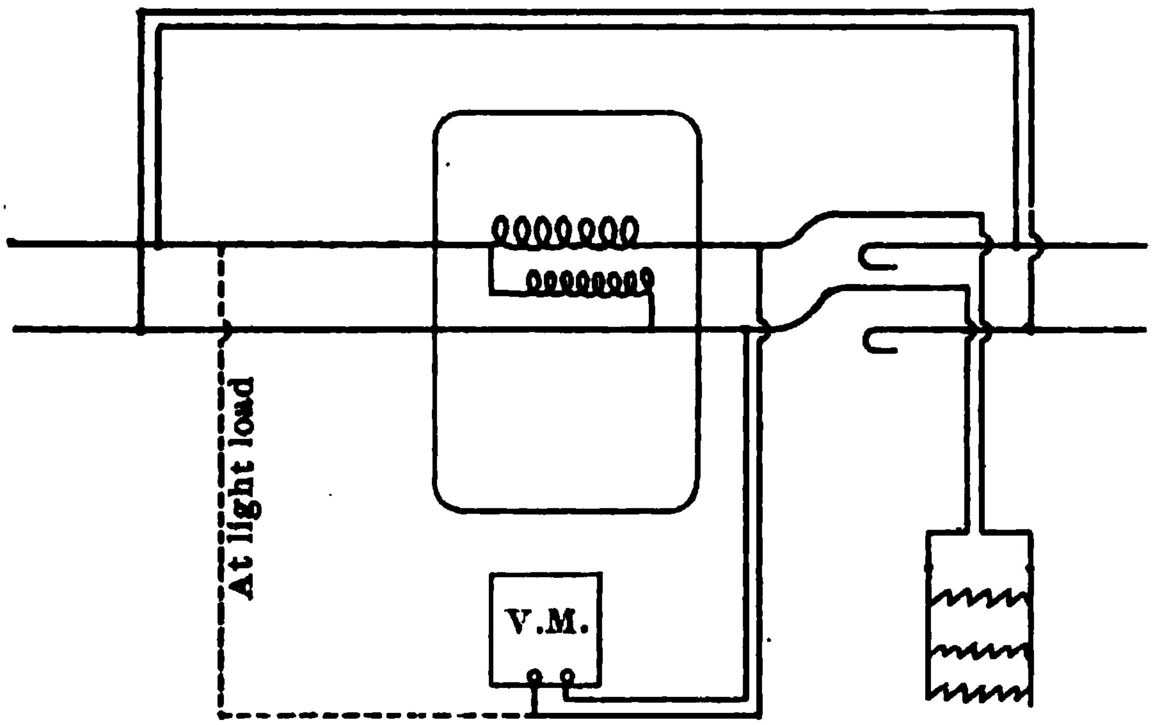


FIG. 273.—Connections for Testing with Calibrated Resistance and Voltmeter.

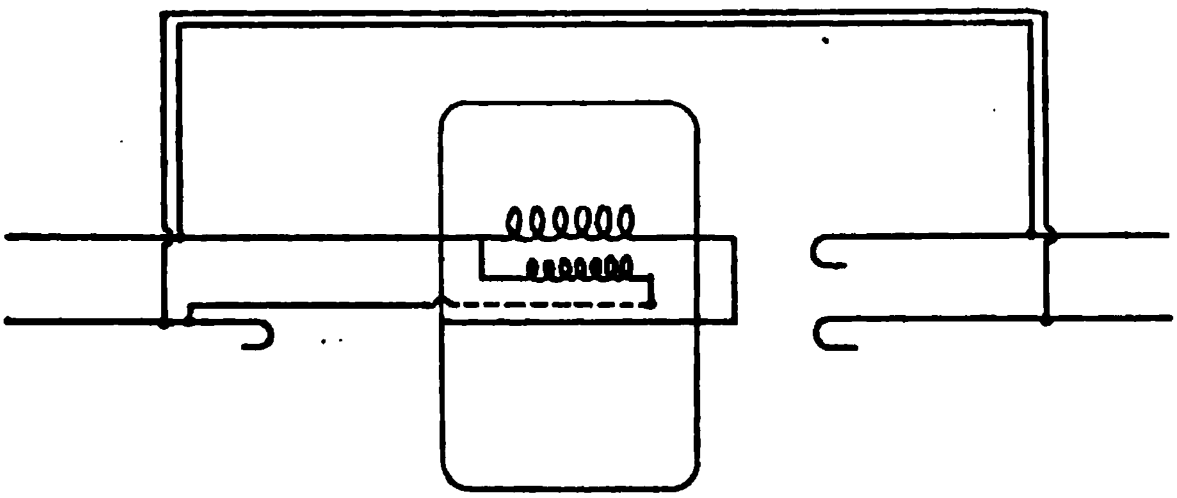


Fig. 274.—Connections Arranged Preparatory to Testing with Storage Battery or Transformer.

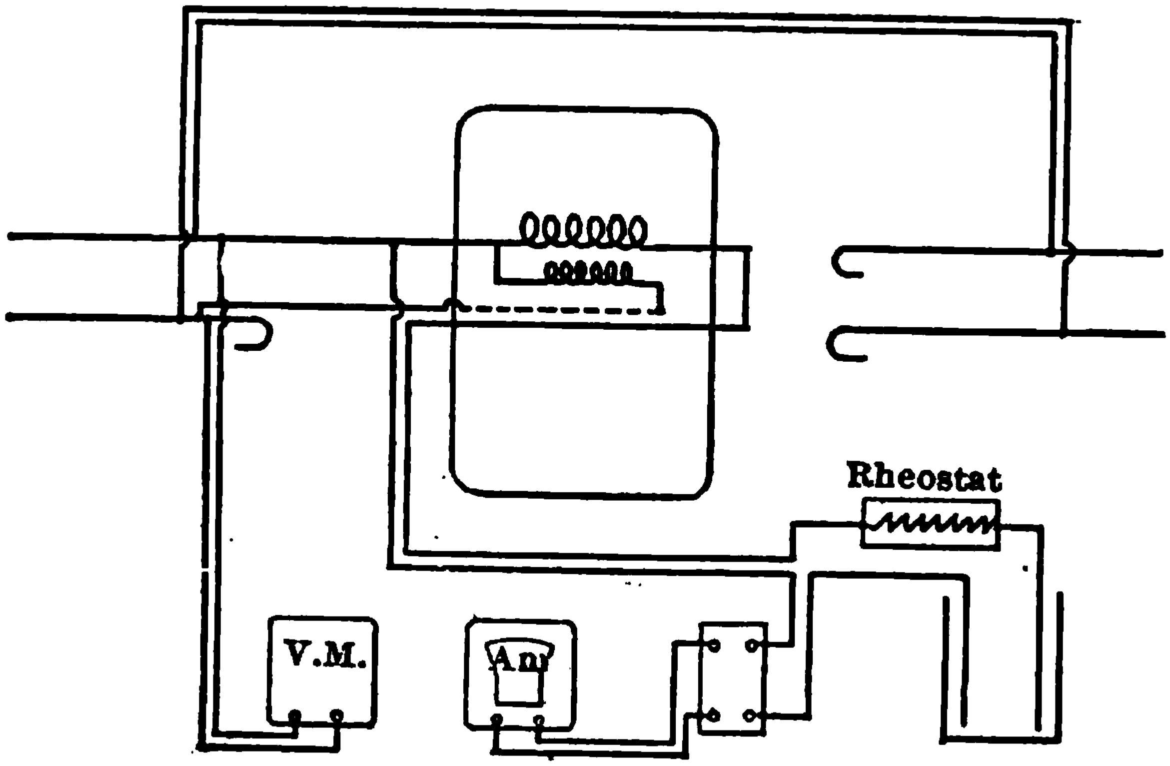


Fig. 275.—Complete Connections for Testing with Voltmeter, Ammeter, and Storage Battery.

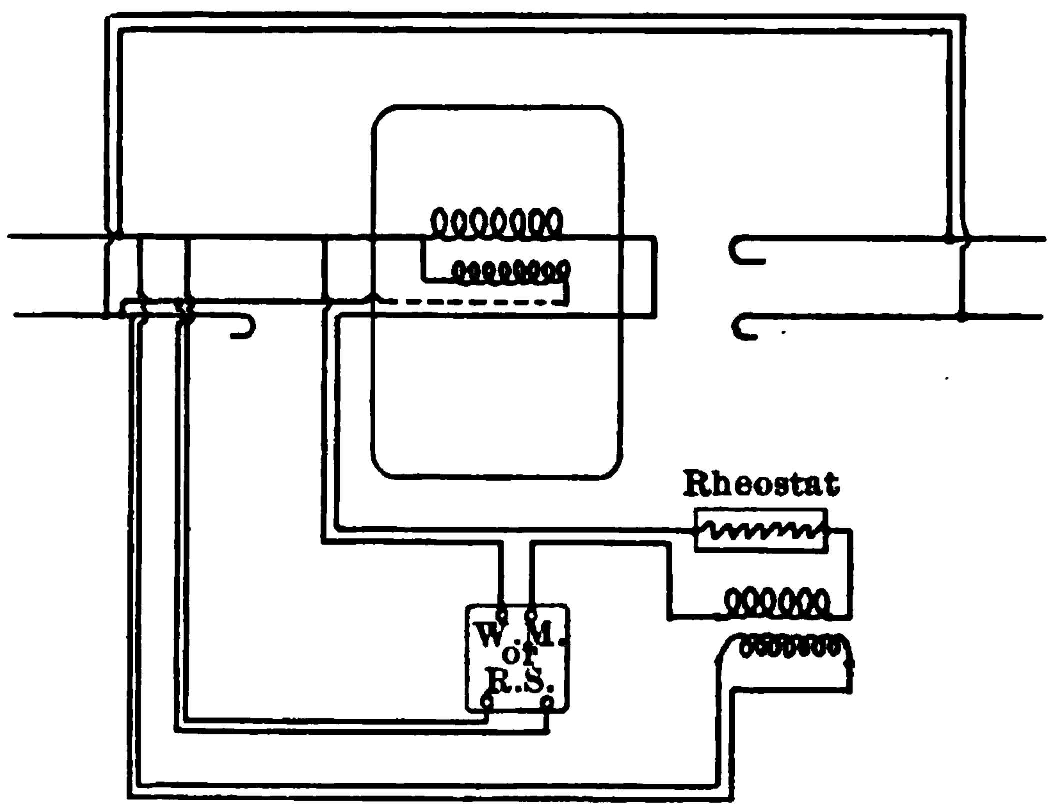


Fig. 276.—Complete Connections for Testing with Wattmeter, Rotating Standard, and Stepdown Transformer

CASE III.—THREE-WIRE WATT-HOUR METER WITH POTENTIAL CIRCUIT ACROSS OUTER WIRES.

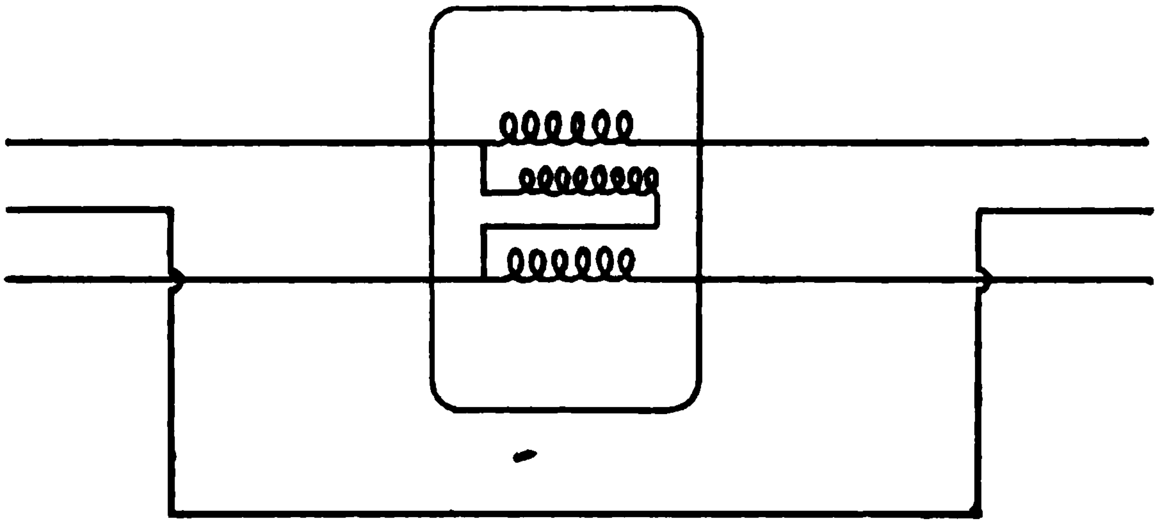


FIG. 277.—Normal Service Connections.

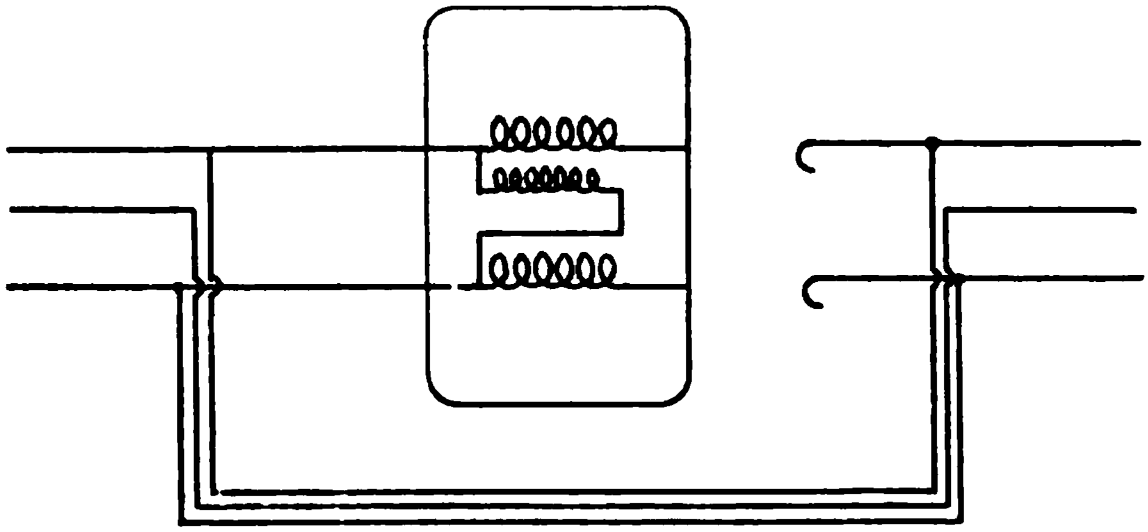


FIG. 278.—Watt-hour Meter Circuit Opened, after Being Shunted.

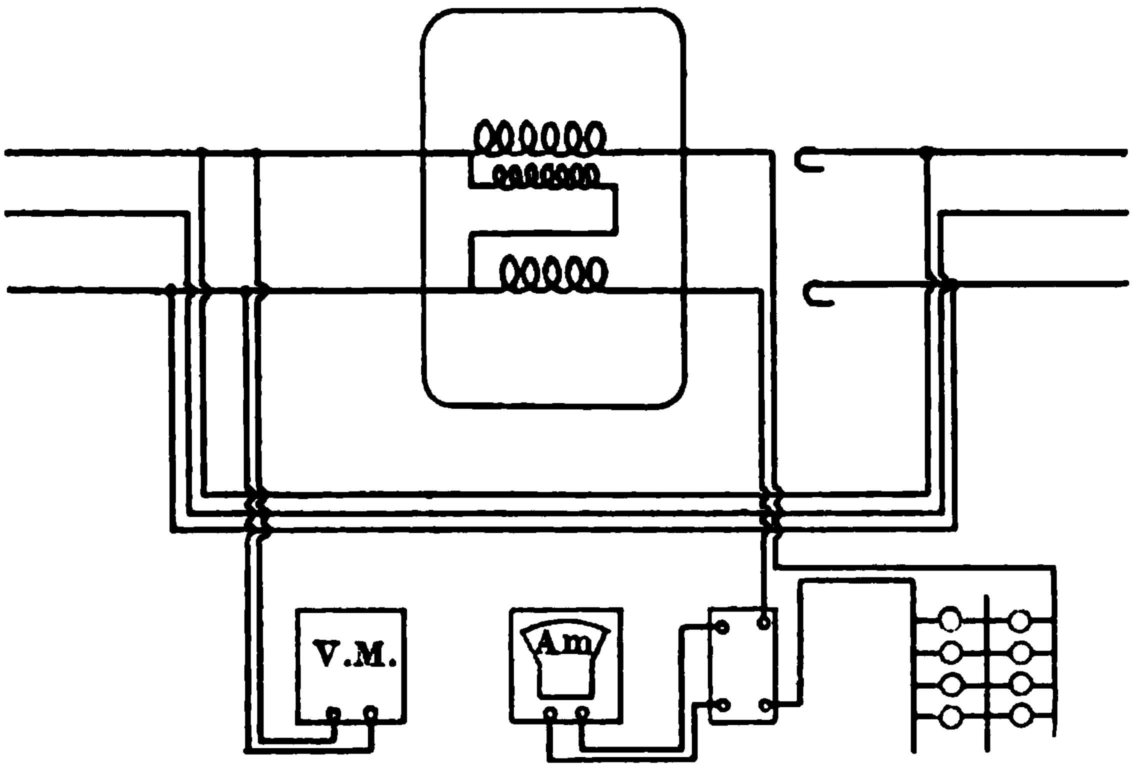


FIG. 279.—Connections for Testing (Service Connections Normal) with Voltmeter and Ammeter and Lamp Bank, Load Box, or Water Rheostat. The Connections for Testing with Wattmeter, Rotating Standard, and Calibrated Resistance are Similar.

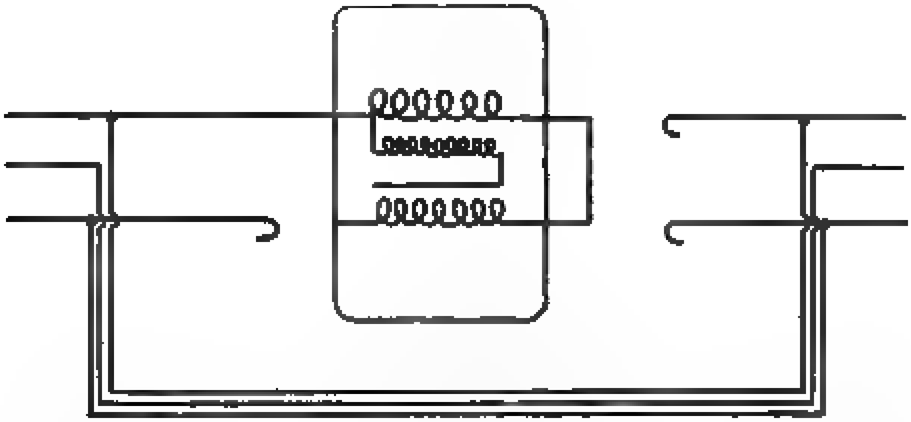


FIG. 280.—Connections Arranged Preparatory to Testing with Coils in Series on Half Potential.

FIG. 281.—Complete Connections for Testing with Coils in Series on Half Potential.

CASE IV.—THREE-WIRE WATT-HOUR METER WITH THE POTENTIAL CIRCUIT BETWEEN THE NEUTRAL AND ONE OUTER WIRE.

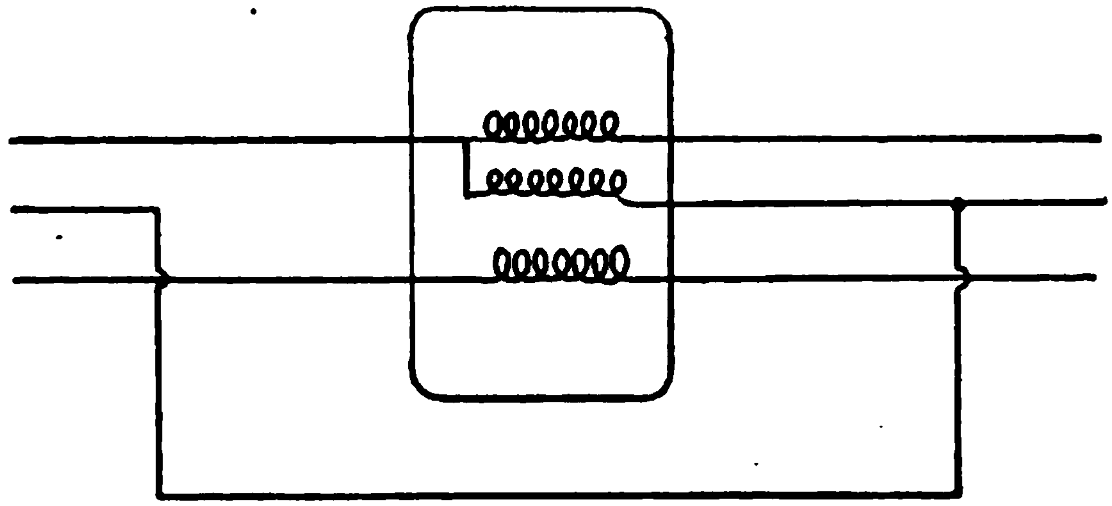


FIG. 282.—Normal Service Connections.

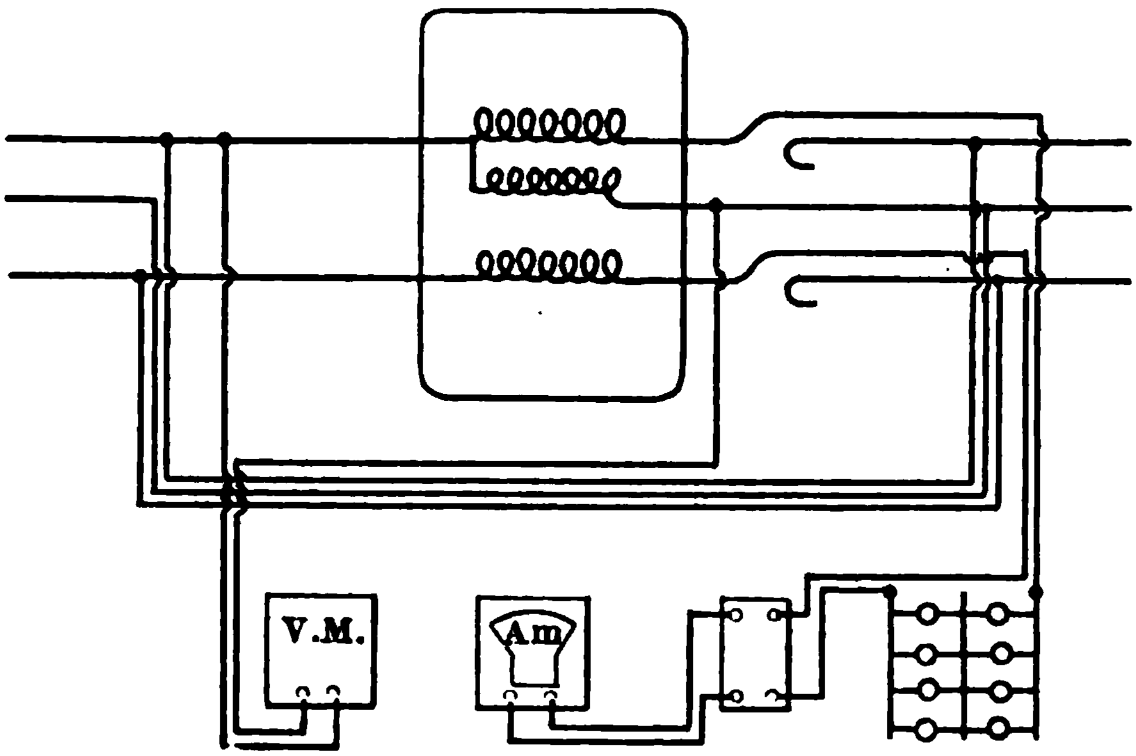


FIG. 283.—Connections for Testing (Service Connections Normal) with Voltmeter and Ammeter and Lamp Bank, Load Box, or Water Rheostat. Connections for Testing with Wattmeter, Rotating Standard, or Voltmeter, and Calibrated Resistance are Similar.

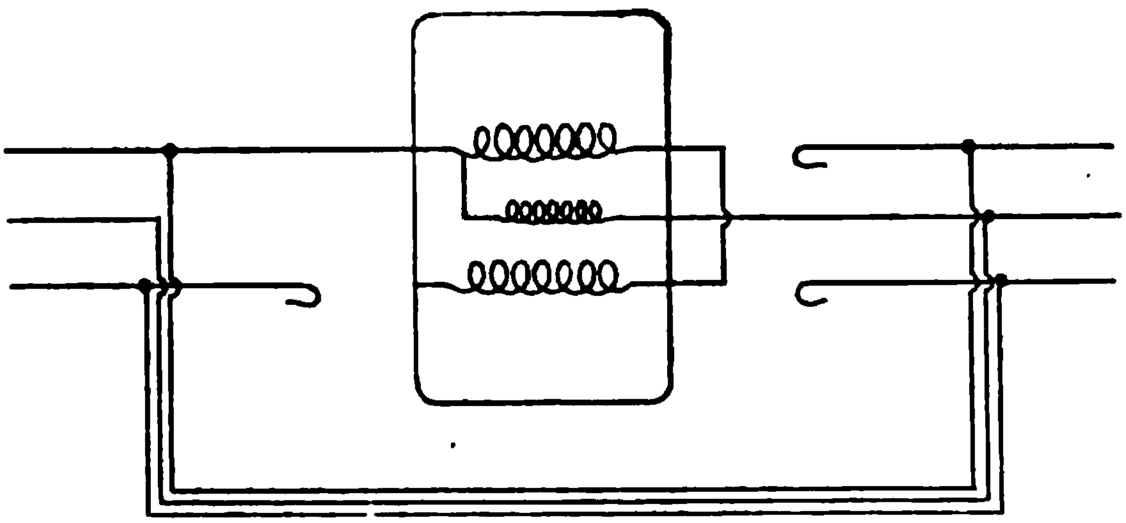


FIG. 284.—Connections Arranged Preparatory to Testing with Coils in Series

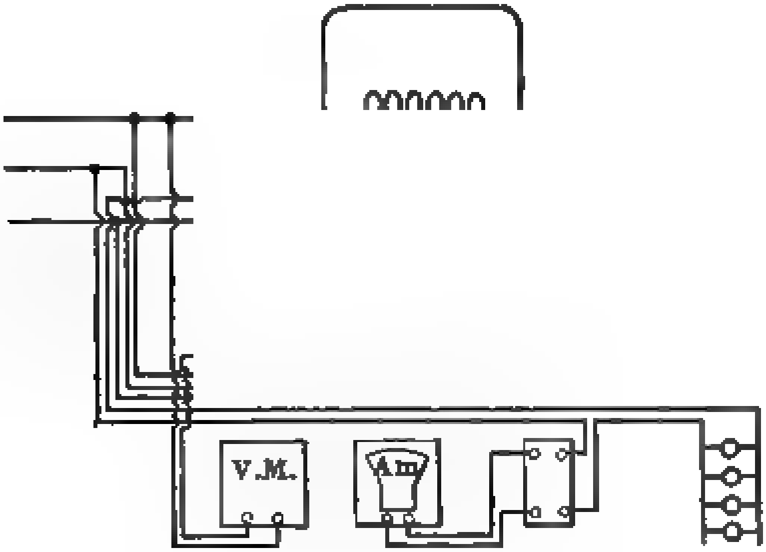


Fig. 285.—Complete Connections for Testing with Coils in Series, on Half Potential, with Indicating Instruments, Wattmeter, or Rotating Standard.

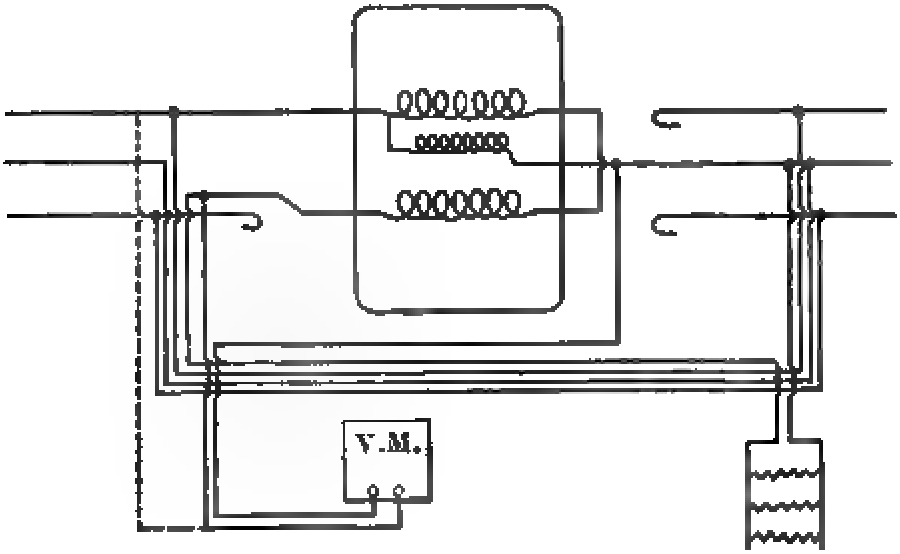


Fig. 286.—Connections for Testing with Calibrated Resistance and Voltmeter.

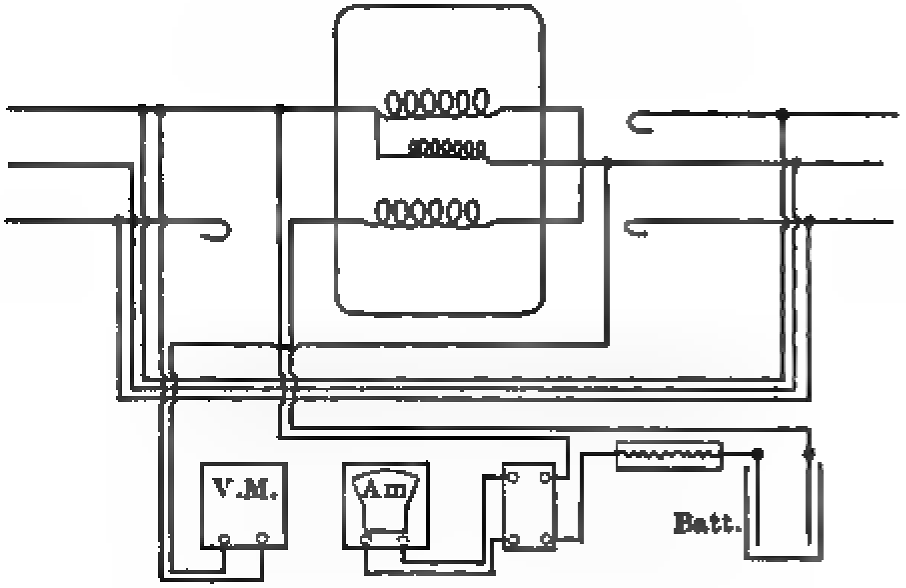


Fig. 287.—Connections for Testing with Voltmeter, Ammeter, and Storage Battery. Connections for Testing with Rotating Standard are Similar.

CASE V.—Polyphase Watt-Hour Meter.

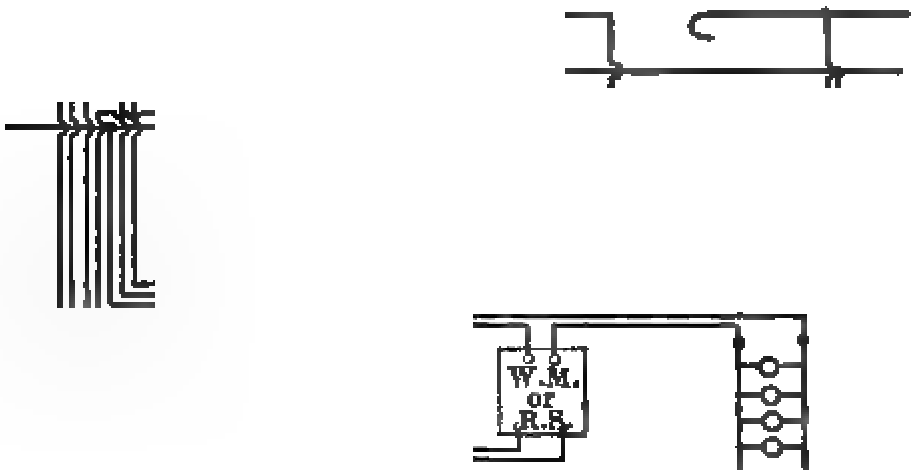


Fig. 288.—Connections for Testing on Single Phase with Current Coils in Series and Potential Circuits in Parallel.

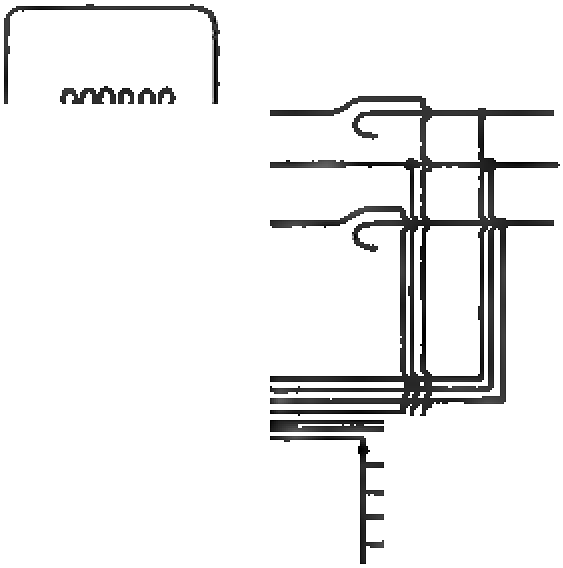


FIG. 289.—Connections for Testing with Two Wattmeters, or Rotating Standards, on a Three-phase "V"-connected Load or a Two-phase Three-wire Circuit.

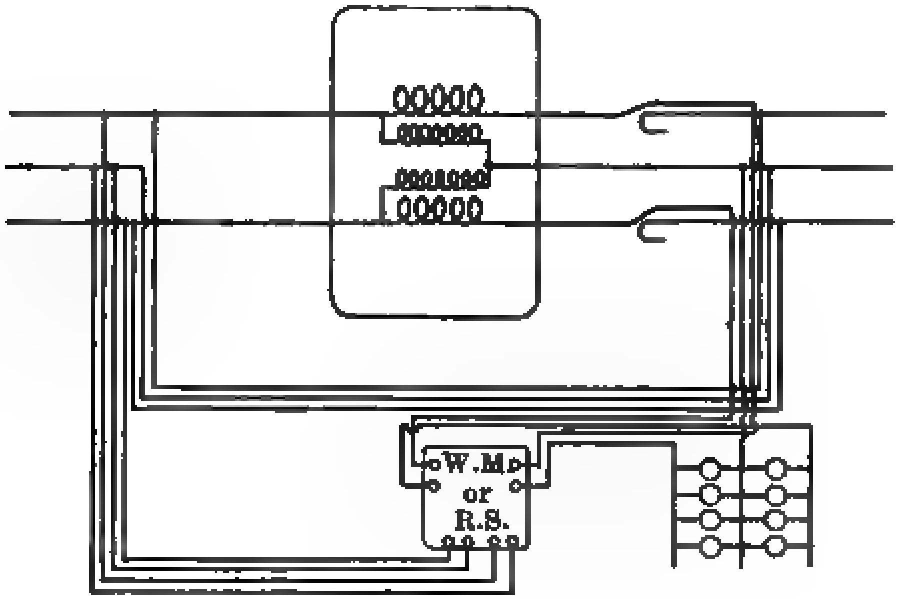


FIG. 290.—Connections for Testing with a Polyphase Standard Wattmeter or Rotating Standard.

CASE VI.—WATT-HOUR METER WITH CURRENT TRANSFORMERS ONLY. LOW PRIMARY VOLTAGE.

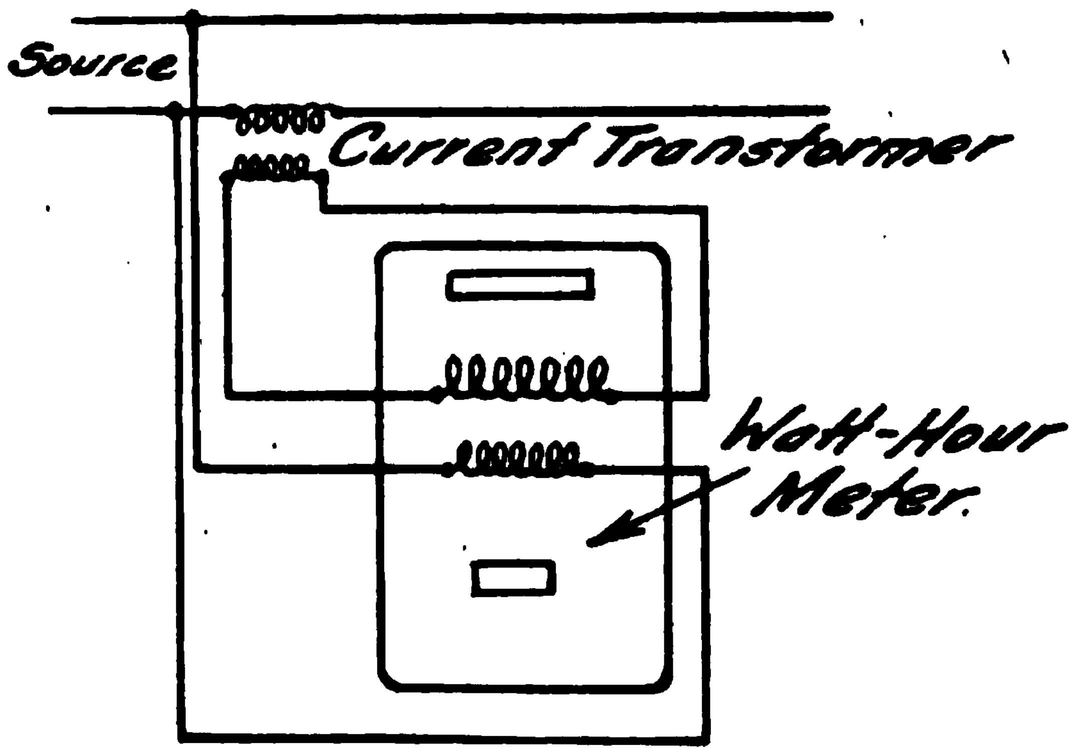


FIG. 291.

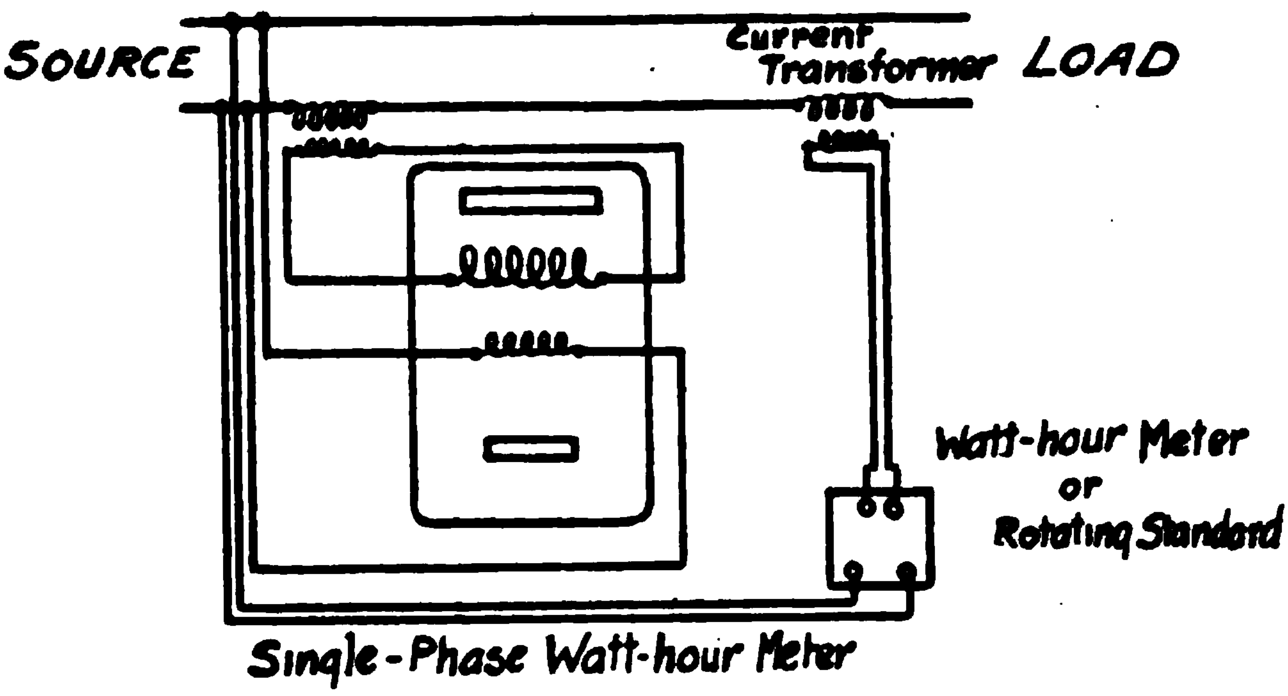


FIG. 292.—Connections for Testing from the Primary with Wattmeter or Rotating Standard and the Consumer's Load.

FIG. 293.—Connections for Testing from the Primary with Wattmeter, Rotating Standard and Stepdown Transformer.

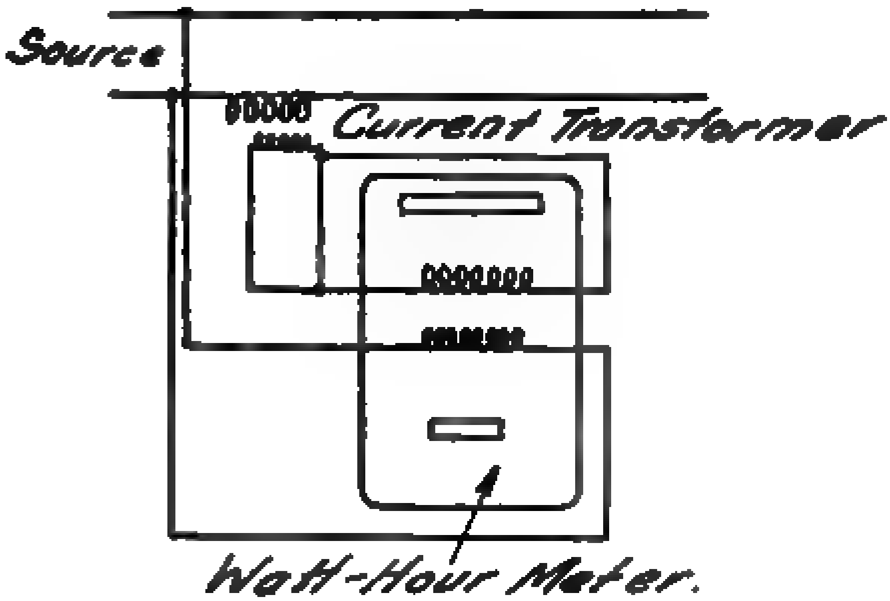


FIG. 294.—Connections for Secondary Test. Secondary of Transformer Short-circuited before Opening Watt-hour Meter Circuit.

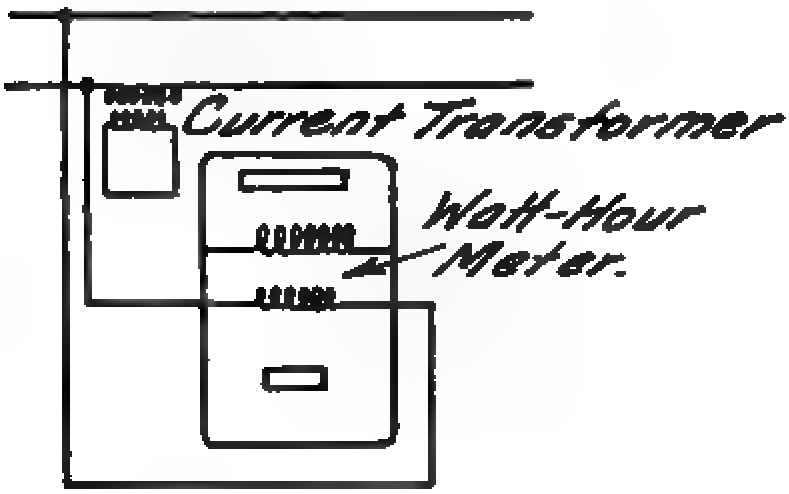


FIG. 295.—Watt-hour Meter Disconnected.

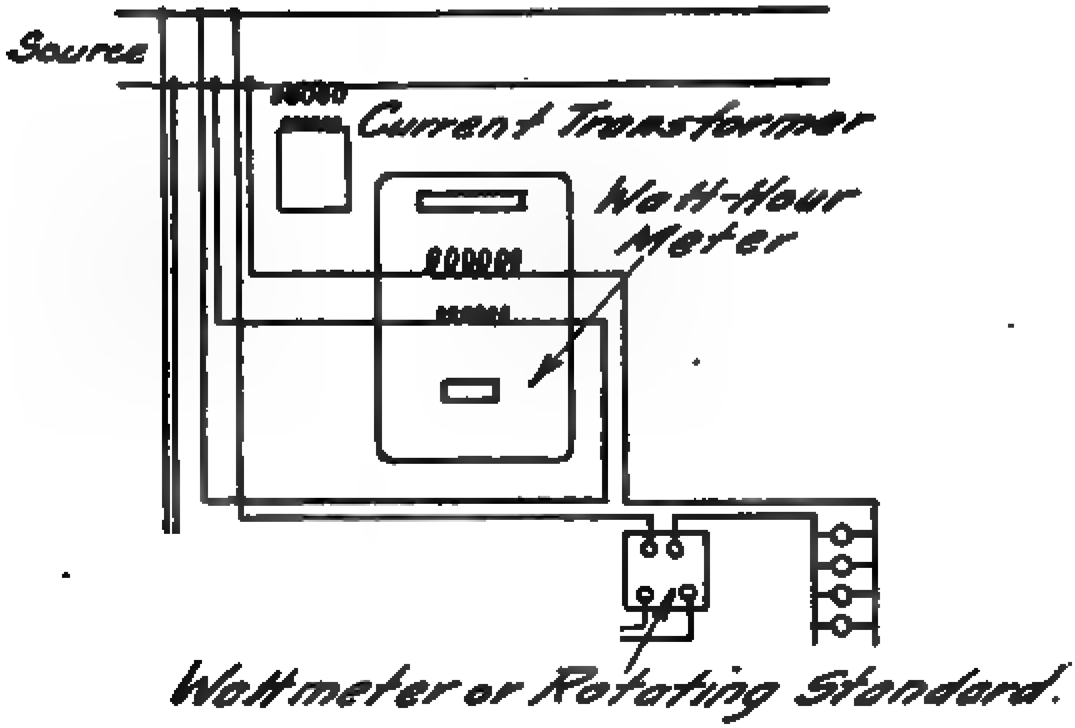


FIG. 296.—Complete Connections for Secondary Test.

CASE VII.—Watt-Hour Meter With Both Current and Voltage Transformers.

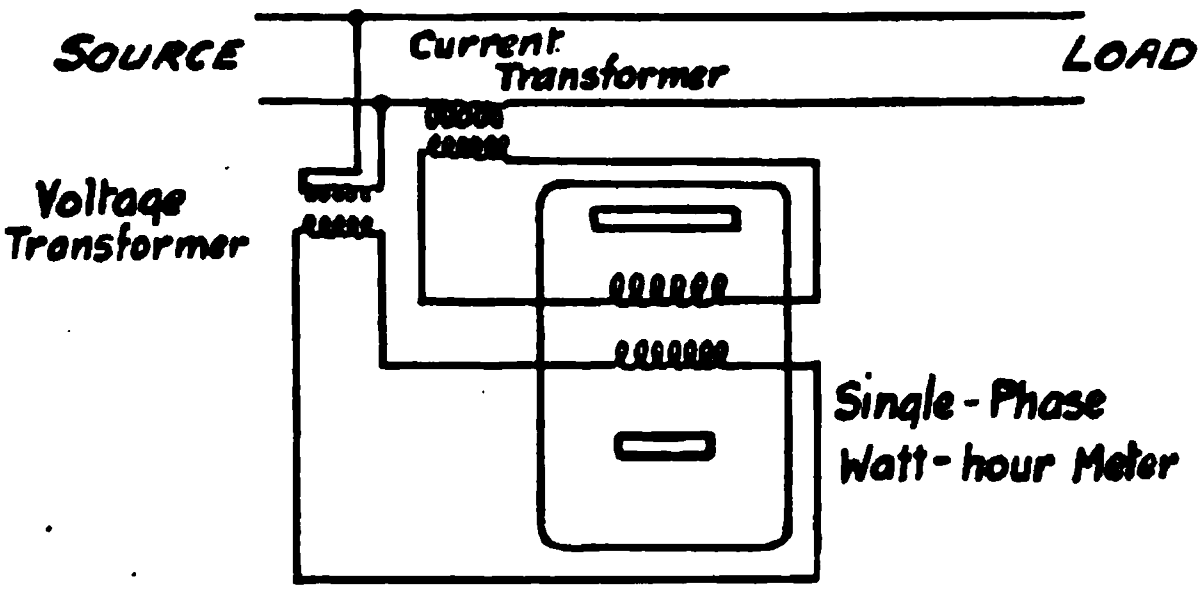


Fig. 297.—Normal Service Connections.

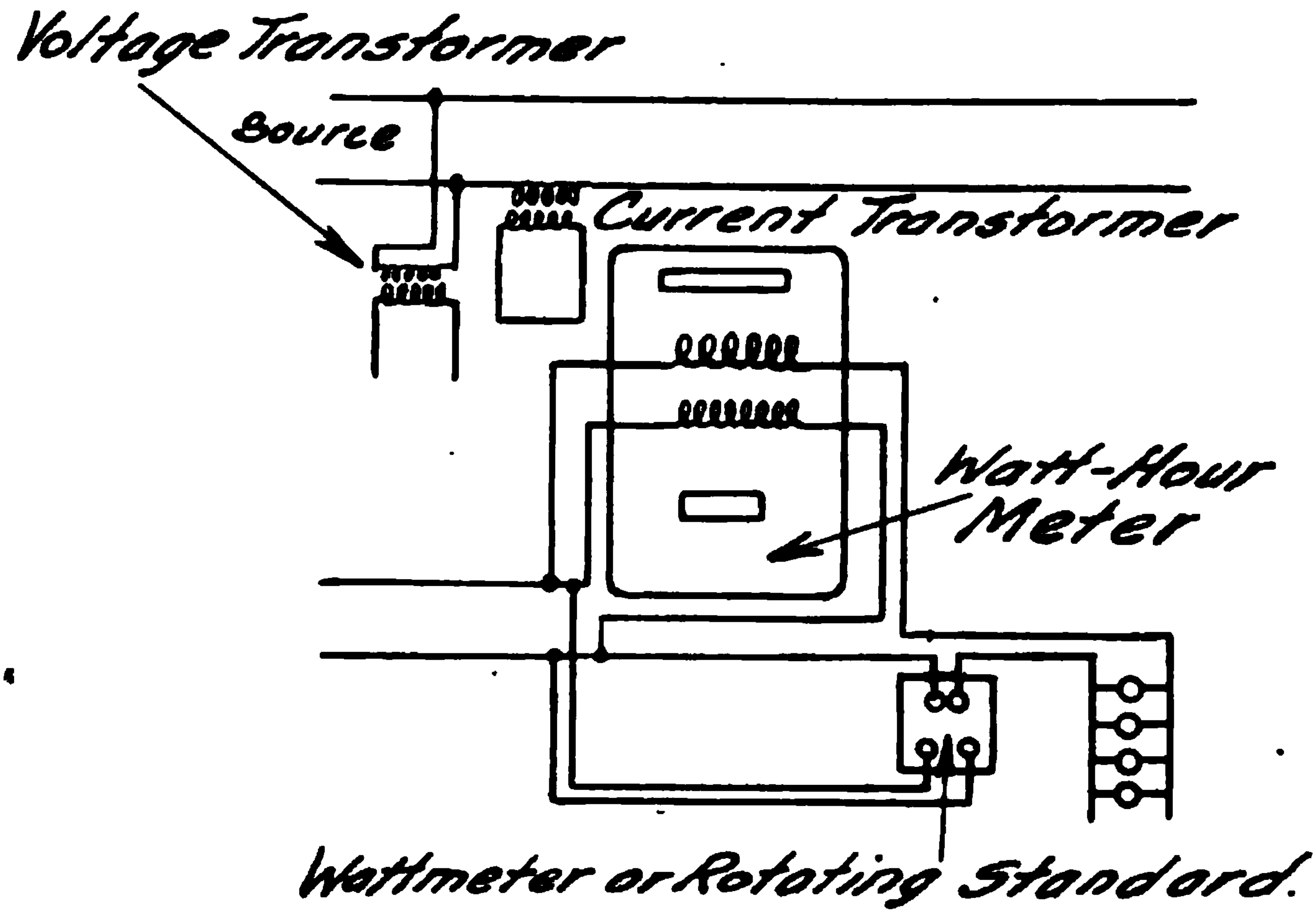


Fig. 298.—Connections for Testing from an Independent Low-voltage Circuit.

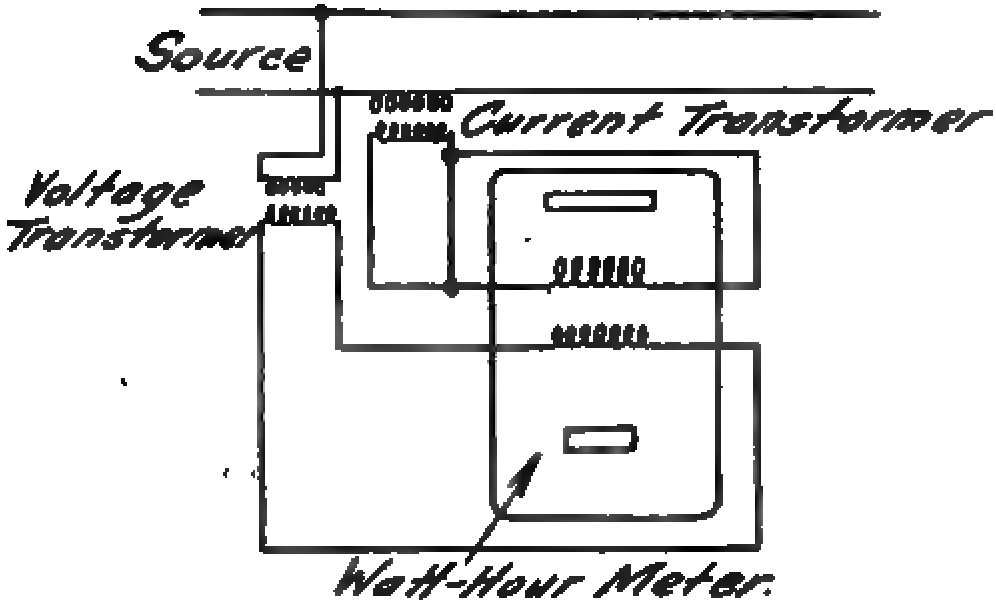


FIG 299.—Connections for Testing from Secondary. Current Transformer Short-circuited.

FIG. 300.—Watt-hour Meter Circuit Open for Connecting Instruments.

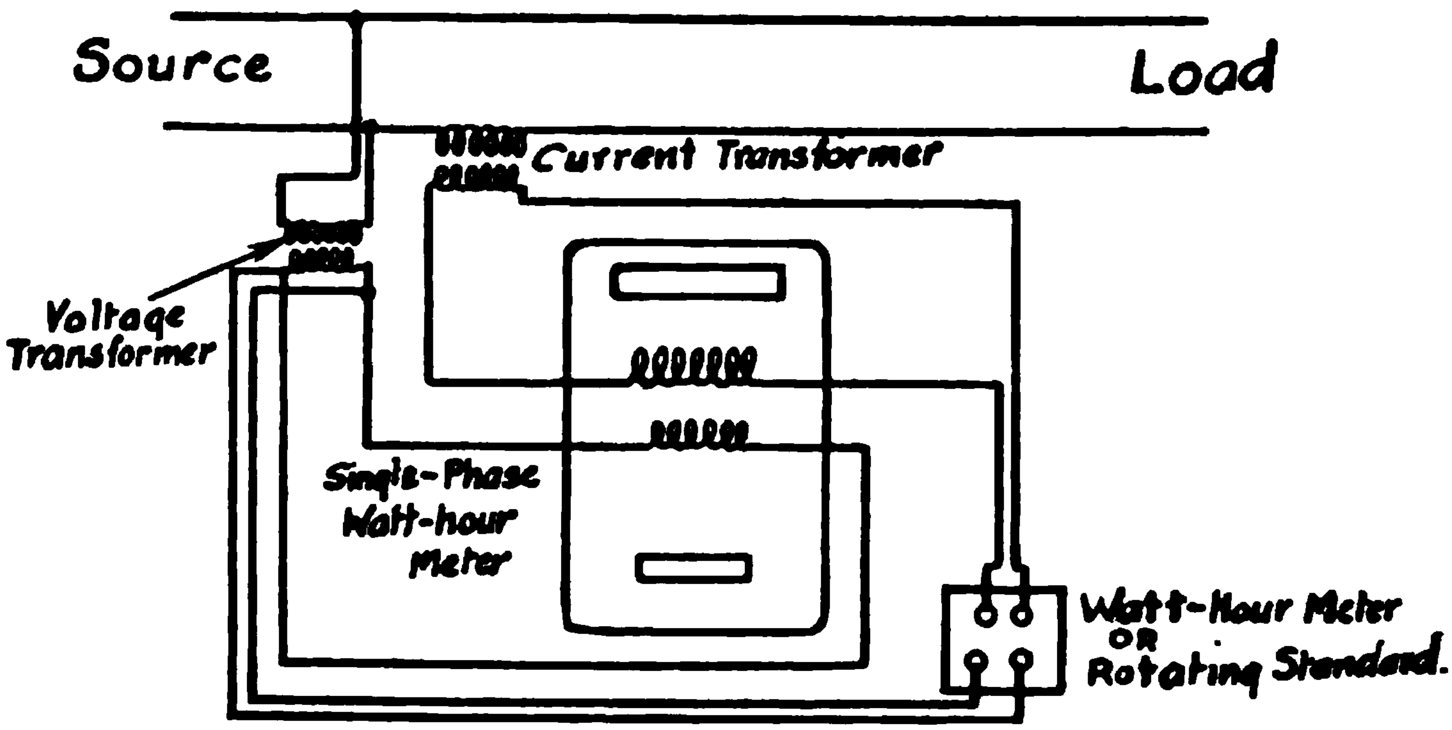


FIG. 301.—Connections for Testing from the Secondary with Wattmeter, Rotating Standard, and the Consumer's Load.

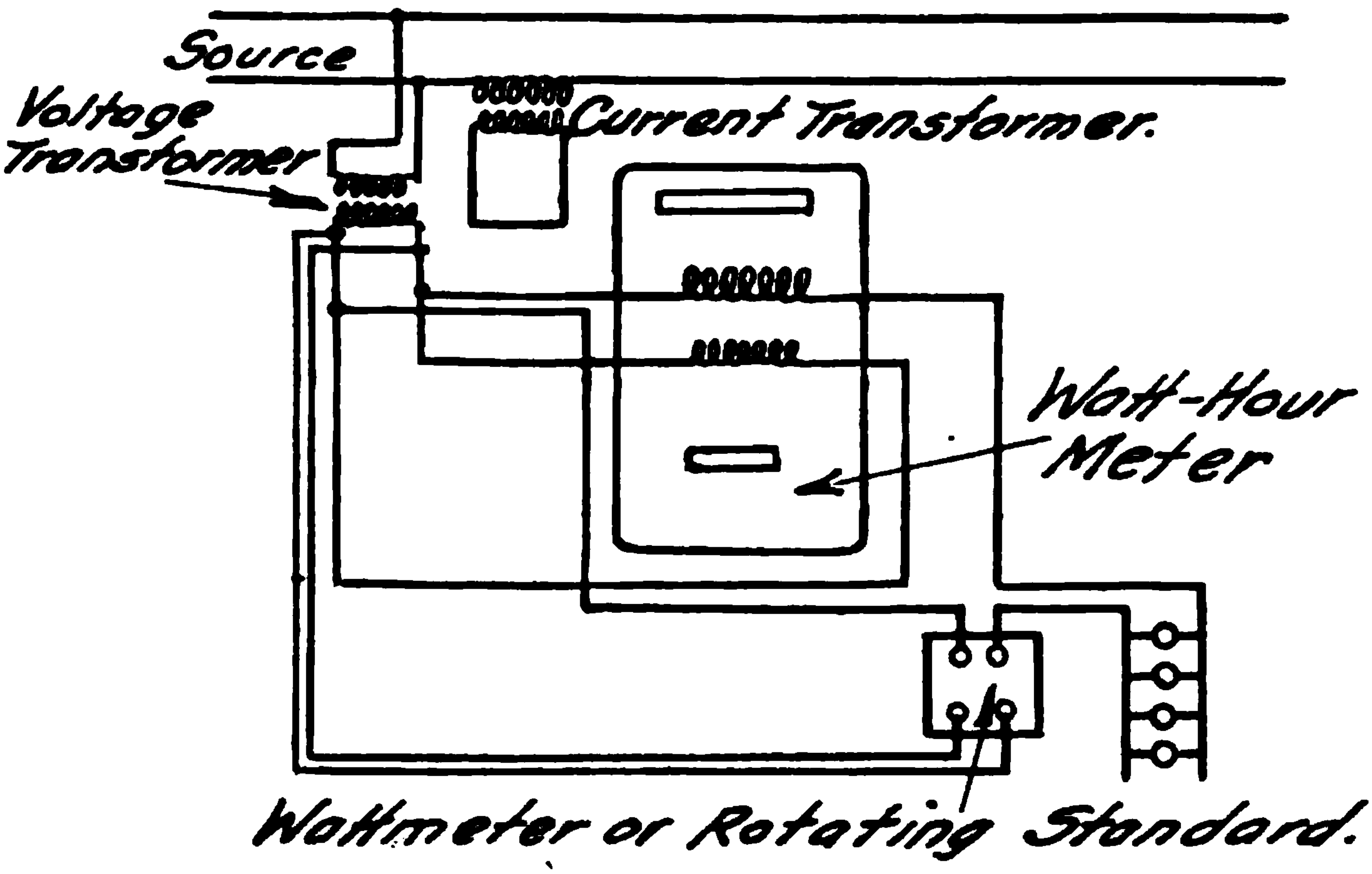


FIG. 302.—Connections for Testing on Light Load from Secondary of Voltage Transformer.

DIAGRAMS OF CONNECTIONS FOR POLYPHASE WATT-HOUR METERS AND INSTRUMENT TRANSFORMERS.

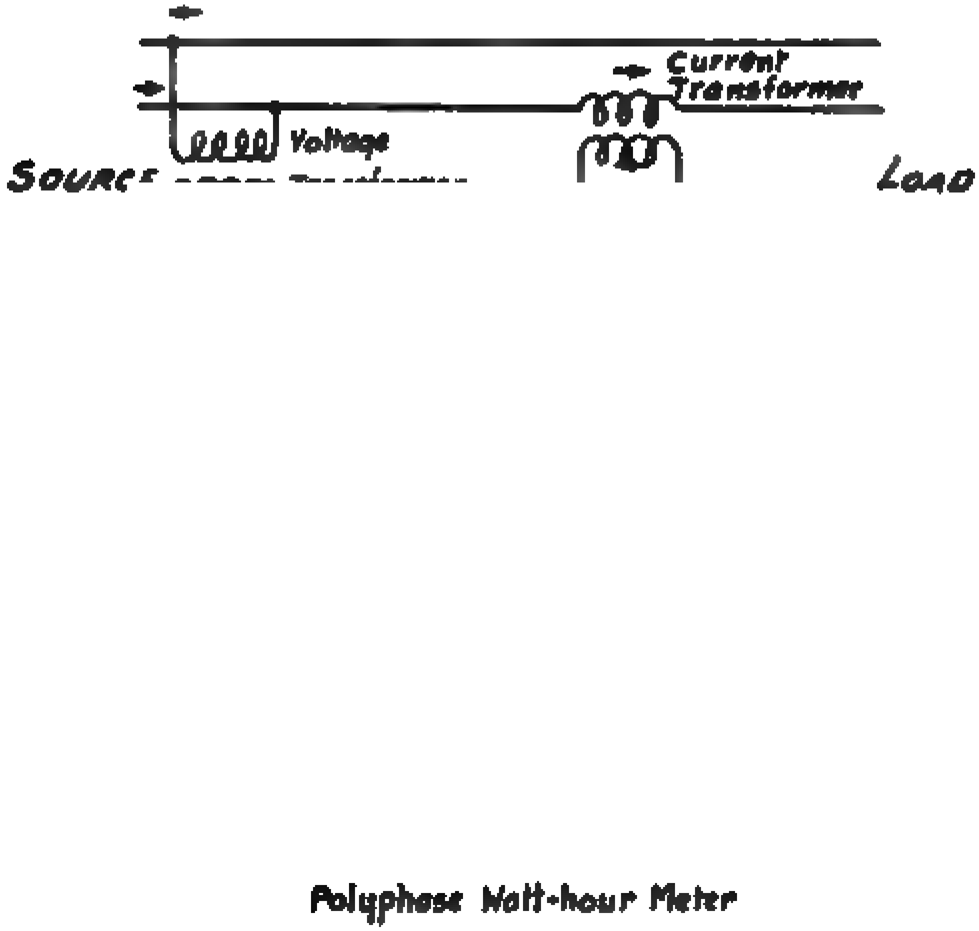


FIG. 303.—Two-phase, Four-wire Circuit. Watt-hour Meter with Current and Voltage Transformers.

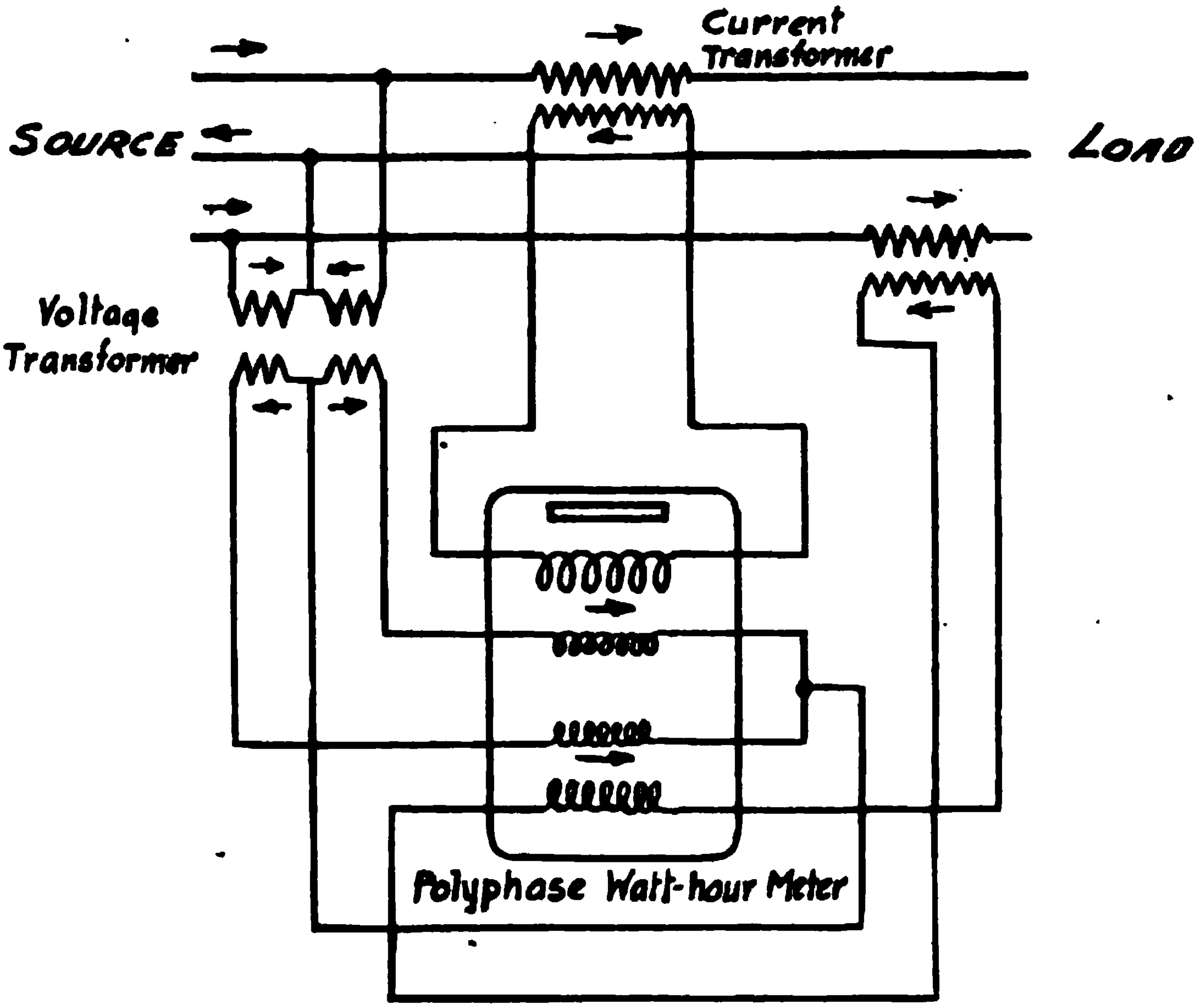


FIG. 304.—Watt-hour Meter with Current and Voltage Transformers.

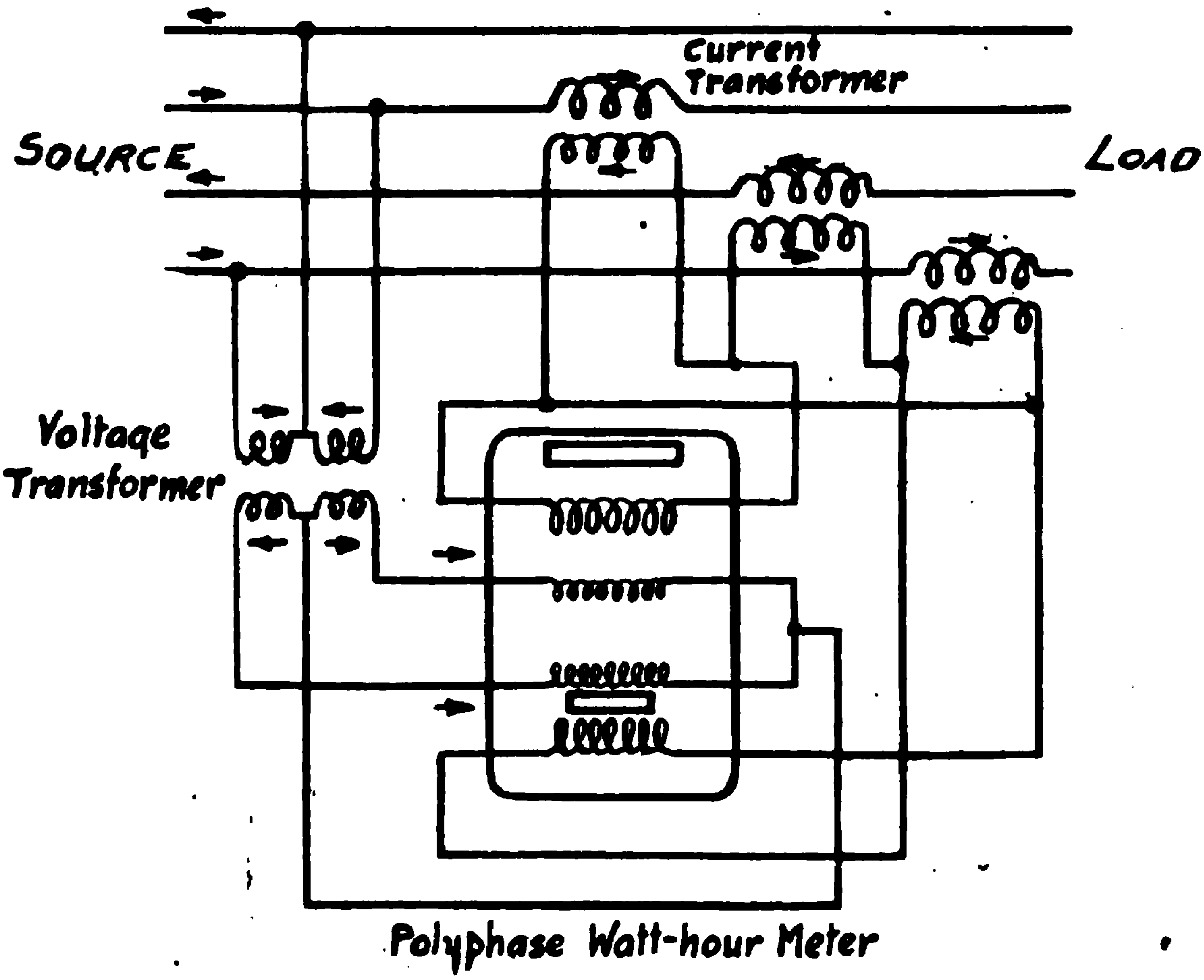


FIG. 305. — Connections for Three-phase, Four-wire Circuit, using Two-element Watt-hour Meter with Voltage Transformers. (Three Current Transformers are Required for all Capacities.)

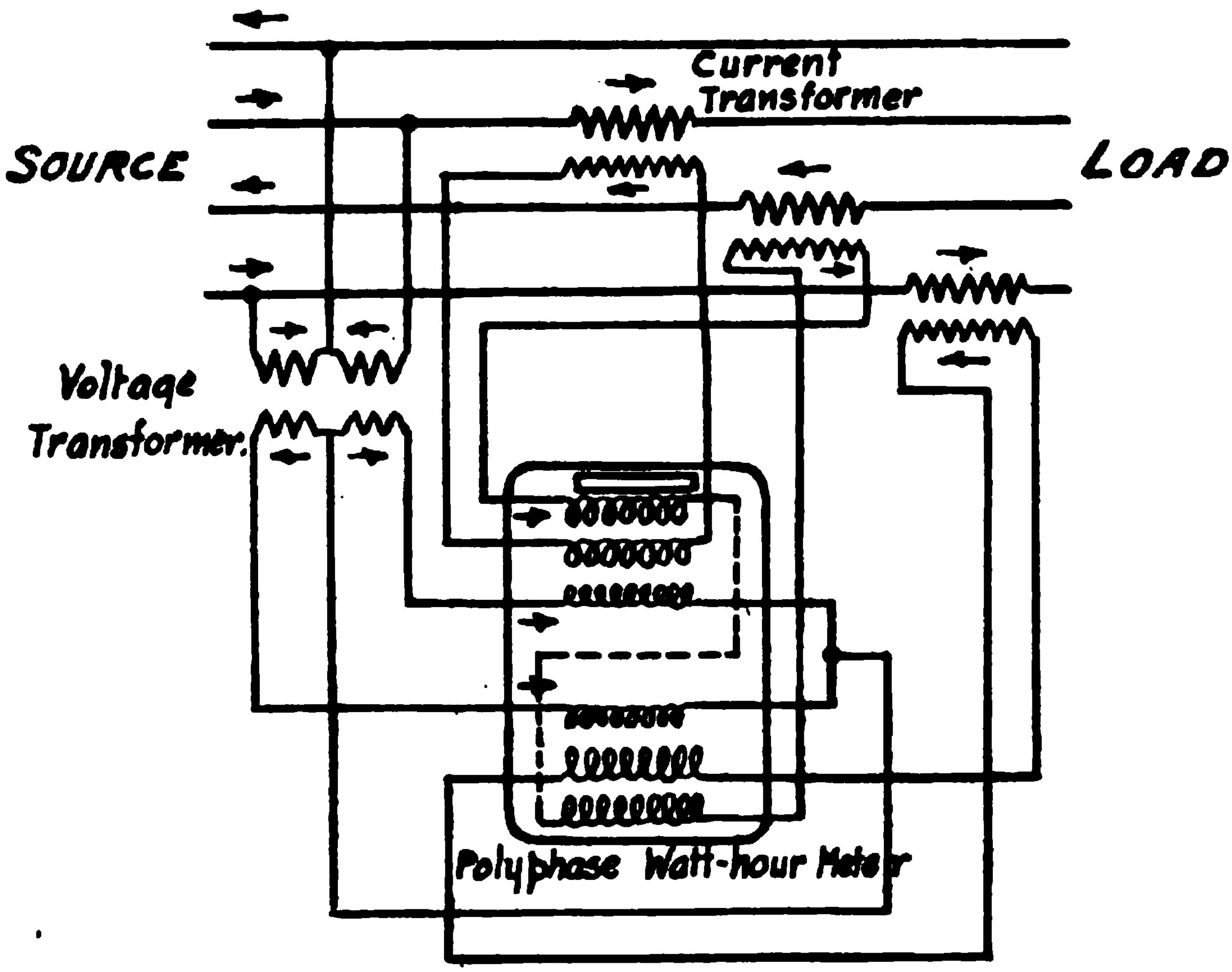


FIG. 306.—Three-phase, Four-wire, Three-element Watt-hour Meter with Current and Voltage Transformers.

CHAPTER VIII

WATT-HOUR METER TESTING METHODS

CHAPTER VIII

Watt-hour Meter Testing Methods

In this chapter it is desired to give such a description of practical and recognized **standard methods of testing** that will enable the meterman to make accurate tests of **watt-hour meters.** Other chapters in this book describe instruments to be used and methods of handling and caring for them; auxiliary apparatus and equipment used in testing; the avoidance of possible errors in testing; troubles to watch for in operation, and adjustments that can be made.

Watt-hour meter-testing methods may be subdivided into three classes, according to the means employed: (1) Indicating Instrument Method; (2) Rotating Standard Method; (3) Calibrated Resistance Method.

In **testing by means of indicating instruments,** a whole number of revolutions of the moving element of the watt-hour meter is timed, in seconds and fractions thereof, with a stop watch. The power passing through the watt-hour meter is measured by the proper indicating instruments. The instruments generally used for continuous current testing are a voltmeter and a millivoltmeter with a combination of shunts calibrated as an ammeter. The above-named instruments should preferably be of the D'Arsonval type. For alternating current work good indicating wattmeters should be used.

In Chapter VII, under accuracy of testing and sources of possible errors, are given hints which will enable accurate work to be done. Chapter V contains a treatise on the instruments to be used.

The meter watts may be figured by the following formula,

$$\text{Meter watts} = \frac{K_s R}{S}$$

K_s = watt-seconds per revolution of moving element of the watt-hour meter = the watt-second constant of the meter under test.
R = number of revolutions in S seconds,
S = duration of test in seconds.

The standard watts are obtained from the volts and amperes in continuous current testing, and are read directly from the wattmeter in alternating current testing, average values being taken if the load fluctuates at all.

$$\text{Percentage of accuracy} = \frac{\text{meter watts}}{\text{standard watts}} \times 100$$

Therefore,

$$\text{Percentage of accuracy} = \frac{K_s R}{S \times \text{standard watts}} \times 100$$

or the percentage of accuracy may be figured by the following formula:

Meter watt-seconds $= K_s R$
Standard watt-seconds $= W\ S$

Where $W =$ average volts $\times$ average amperes during S seconds, as read from the instruments, or equals the average reading of wattmeter, where a wattmeter is used.

$$\text{Then percentage of accuracy} = \frac{K_s R}{W\ S} \times 100$$

Examples showing how to use both these formulas are given in Chapter VII.

In Chapter VII are also shown proper connections for making tests by this method. It will be noticed that all connections are made so that the watt-hour meter does not measure the potential loss of the instruments, or the instruments measure the potential loss of the watt-hour meter.

If the instruments are more than 0.3 per cent in error, correction charts, or curves, should be supplied and corrections applied to readings before the entry is made on test forms, and before the results are figured. Stop watches, which are found in error, should be corrected. The stop watches used should be compared daily with a pendulum which accurately beats seconds. The instruments should be referred to sub-standards at such frequent intervals as will insure their continued accuracy.

It is considered good practice to use artificial loads for testing purposes. Some of these devices are described in Chapter IX. This practice permits of the consumer's load being shunted and provides a convenient means of controlling the testing load.

It is advisable to use two men when testing by means of indicating instruments. One to watch and read the instruments, and the other to

time the revolutions of the moving element of the watt-hour meter under test.

The **work** may be **divided** between the two men as follows:

Tester	Assistant
(1) Checks watt-hour meter number with that on test form; takes and enters register reading of watt-hour meter; cleans and removes cover; makes necessary connections for test and examines watt-hour meter for creeping.	(1) Checks watt-hour meter register reading; sets up instruments in a safe place, as free from vibration, magnetic influence and liability to mechanical injury as possible; gets leads and apparatus in condition for use in making connections.
(2) Reads instruments; figures percentage of accuracy of watt-hour meter by means of slide rule, and makes proper entry "as found" on test form.	(2) Times speed of moving element of watt-hour meter with stop watch.
(3) Examines jewel and pivot; cleans inside of watt-hour meter, if necessary, and thoroughly examines meter for defects.	(3) Hands necessary jewels, tape and tools to tester, trying to anticipate his wants. Cleans cover and glass window thoroughly.
(4) Recalibrates the watt-hour meter, if necessary; enters operations and "as left" tests on the test form and again examines watt-hour meter for creeping.	(4) Times speed of moving element of watt-hour meter with stop watch, and, if competent, makes adjustments under directions of the tester.
(5) Properly reconnects watt-hour meter; examines cover for holes and defects; replaces cover; takes and enters register reading on test form; inspects watt-hour meter through glass window, to see if it is recording; examines connections to consumer's load to see that there is no break in circuit and enters special observations under "Remarks" on test form.	(5) Hands tester the cover and sealing appliances and packs tools, instruments and apparatus for transportation to next place.

The above is not given as universal practice but is cited here for the purpose of recommending systematic work, so that there will be a minimum of unprofitable time spent by each meterman.

Rotating standards are made with multiple current coils and generally for two different potentials, such as 110 and 220 volts. The object of this is to so select a current coil that the rotating standard will never operate on very low percentage loads, or on overloads, and also to select a proper potential coil. It is best to have them operating between 50 per cent and 100 per cent load especially when using continuous current rotating standards. They are now made with some such range of capacities of current coils as follows: 1, 5, 10, 50 and 100 amperes, or 1, 3, 10, 30 and 100 amperes.

Rules for use accompany each rotating standard and should be thoroughly learned and understood before attempting to use the instrument.

The connections for testing are the same as with instruments, i. e., the current coil is connected the same as an ammeter, or the current coil of an indicating wattmeter, and the potential coil the same as a voltmeter, or the potential coil of an indicating wattmeter would be. However, as the potential circuit of rotating standards require more current than indicating instruments, more care should be taken to make good electrical contacts with the potential leads.

When setting up a rotating standard for the purpose of making a test, a place should be selected as free from vibration and magnetic influence as possible. The current leads should go to, and from, the standard close together so that there will be no resultant magnetic field produced by them. Avoid proximity to masses of iron, motors, electrical apparatus and to conductors carrying heavy currents. These precautions should be more carefully observed with continuous than with alternating current rotating standards. In addition, the continuous current rotating standards should always have their positive leads connected to the positive binding posts and should always be placed with the plane of their current coils in the direction indicated by a compass needle. The plane of the current coils should always be parallel to the direction in which a compass needle points, with the current and potential coils of the rotating standard "dead," and the relative directions of rotating standard and compass needle should always be the same. Care should be taken to level the rotating standard.

Two single-phase rotating standards may be used for testing two-phase watt-hour meters, and three-phase, three-wire watt-hour meters, by placing one rotating standard in each phase, in a manner similar to that in which two indicating wattmeters would be connected in the indicating instrument method. They may be started and stopped by using a double

controlling switch. If one rotating standard rotates backward, on a three-phase three-wire test, without having its current, or potential connections reversed, it indicates that the power-factor of the load is below .50. The rotating standard should not be used rotating backward, for it will register low on account of the friction compensating torque opposing rotation. Either the current, or the potential, connections should be reversed, thus causing that rotating standard to rotate forward, and its registration subtracted from the registration of the other rotating standard. A polyphase rotating standard may be used instead of two of the single-phase type, provided it has been found free from the effects of interference between elements. Where the difference between the accuracy of a rotating standard, as checked on single-phase, and its accuracy as checked on polyphase, does not exceed 0.5 per cent, it may be calibrated on a single-phase circuit. If the difference between the above accuracies, on single-phase and polyphase, exceeds 0.5 per cent at any point in the working range, the rotating standards should be calibrated with a polyphase load of the same number of phases as that on which they are used in service. This difference, if present, will increase as the power-factor decreases.

Several different methods of testing watt-hour meters by means of rotating standards are practised by various companies. These will be described as

a. The Switch Method.
b. The Philadelphia Electric Method.
c. The Wheatstone Bridge Method.

The switch method is that in which the rotating standard, or the dial hand of the standard, is started and stopped at the beginning and end of each test reading. This is accomplished in alternating current standards by a switch in the potential circuit, the operation of which starts or stops the standard. In continuous current rotating standards, a switch in the potential circuit is used in the type whose accuracy is not altered by the heating of the potential circuit. In those types of continuous current rotating standards in which the heating of the potential circuit affects the accuracy, the standard is started and stopped by a switch in the current or field circuit, or the rotating standard runs continuously and the dial hand is engaged or disengaged by a magnetic clutch, the circuit of which is connected across the line potential and opened or closed by a switch.

In all these types, the switch is connected to the standard by a flexible cord, so that it can be operated by the tester from his position at the meter under test. The method of procedure is the same, so that one description will apply to all cases (Fig. 307).

By the **potential switch method of testing watt-hour meters by means of a rotating standard,** the latter is started at the beginning and stopped at the end of a predetermined number of revolutions of the watt-hour meter under test. A reading of the rotating standard is taken at the beginning and end of the test and the difference

Fig. 307.—Application of the Potential Switch Method of Watt-hour Meter Testing.

of these two readings gives the revolutions and fractions thereof made by the rotating standard. (It is an easy matter to set the rotating standard, when starting a given test, at some even number of revolutions, thus facilitating the taking of this difference.)

If no correction is to be applied to the rotating standard, the percentage of accuracy of the watt-hour meter under test is obtained as follows:

Let R = observed revolutions of watt-hour meter under test (abbreviated meter revs.)
R_x = observed revolutions of rotating standard.
K_h = watt-hour constant of meter under test.
K'_h = watt-hour constant of rotating standard.

$$\text{Then percentage of accuracy} = \frac{K_h R}{K'_h R_x}$$

Another method of figuring percentage of accuracy, somewhat simpler after being used, is as follows:

Let R_o = correct revolutions of rotating standard (abbreviated, stand. revs.), that is the number of revolutions the rotating standard should make to correspond with the ratio of K_h to K'_h as shown in Tables.

$$\text{Then percentage of accuracy} = \frac{R_o}{R_x} \times 100.$$

Since the number of revolutions for a given amount of energy measured is inversely proportional to the watt-hour constant.

When a correction is to be applied for the error in the rotating standard this percentage error is added to the result in case the rotating standard is fast, or subtracted from it in case the rotating standard is slow.

Example:

Watt-hour meter under test, $K_h = 0.5$ watt-hr. per rev.
Rotating standard $K'_h = 0.05$ watt-hr. per rev.

The rotating standard should therefore make 10 revolutions to one of the watt-hour meter under test. (See table). Two revolutions of meter under test were taken and the rotating standard made, during same period, 20.16 revolutions, but should have made 2×10, or 20 revolutions, if the watt-hour meter had been accurate.

$$\text{Percentage of accuracy} = \frac{20}{20.16} \times 100 = 99.2\%.$$

This can be calculated by one setting of slide rule.

TABLES SHOWING RELATIVE SPEEDS OF ROTATING STANDARD AND WATT-HOUR METER UNDER TEST

Rotating Standard Constants = K_h	Watt-Hour Meter Constants = K_h										
	0.125	0.2	$\frac{5}{24}$	0.25	0.3	$\frac{1}{3}$	$\frac{3}{8}$	0.4	$\frac{5}{12}$	0.5	0.625
0.05	$\frac{*5}{*2}$	$\frac{4}{1}$	$\frac{25}{6}$	$\frac{5}{1}$	$\frac{6}{1}$	$\frac{20}{3}$	$\frac{15}{2}$	$\frac{8}{1}$	$\frac{25}{3}$	$\frac{10}{1}$	$\frac{25}{2}$
0.10	$\frac{5}{4}$	$\frac{2}{1}$	$\frac{25}{12}$	$\frac{5}{2}$	$\frac{3}{1}$	$\frac{10}{3}$	$\frac{15}{4}$	$\frac{4}{1}$	$\frac{25}{6}$	$\frac{5}{1}$	$\frac{25}{4}$
0.15	$\frac{5}{6}$	$\frac{4}{3}$	$\frac{25}{18}$	$\frac{5}{3}$	$\frac{2}{1}$	$\frac{20}{9}$	$\frac{5}{2}$	$\frac{8}{3}$	$\frac{25}{9}$	$\frac{10}{3}$	$\frac{25}{6}$
0.2	$\frac{5}{8}$	$\frac{1}{1}$	$\frac{25}{24}$	$\frac{5}{4}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	$\frac{2}{1}$	$\frac{25}{12}$	$\frac{5}{2}$	$\frac{25}{8}$
0.25	$\frac{1}{2}$	$\frac{4}{5}$	$\frac{5}{6}$	$\frac{1}{1}$	$\frac{6}{5}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{8}{5}$	$\frac{5}{3}$	$\frac{2}{1}$	$\frac{5}{2}$
0.3	$\frac{5}{12}$	$\frac{2}{3}$	$\frac{25}{36}$	$\frac{5}{6}$	$\frac{1}{1}$	$\frac{10}{9}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{25}{18}$	$\frac{5}{3}$	$\frac{25}{12}$
$\frac{1}{3}$	$\frac{3}{8}$	$\frac{3}{5}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{9}{10}$	$\frac{1}{1}$	$\frac{9}{8}$	$\frac{6}{5}$	$\frac{5}{4}$	$\frac{3}{2}$	$\frac{15}{8}$
0.4	$\frac{5}{16}$	$\frac{1}{2}$	$\frac{25}{48}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{5}{6}$	$\frac{15}{16}$	$\frac{1}{1}$	$\frac{25}{24}$	$\frac{5}{4}$	$\frac{25}{16}$
0.5	$\frac{1}{4}$	$\frac{2}{5}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{3}{5}$	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{4}{5}$	$\frac{5}{6}$	$\frac{1}{1}$	$\frac{5}{4}$
$\frac{2}{3}$	$\frac{3}{16}$	$\frac{3}{10}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{9}{20}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{5}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{15}{16}$
1.0	$\frac{1}{8}$	$\frac{1}{5}$	$\frac{5}{24}$	$\frac{1}{4}$	$\frac{3}{10}$	$\frac{1}{3}$	$\frac{3}{8}$	$\frac{2}{5}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{5}{8}$
$1\frac{1}{3}$	$\frac{3}{32}$	$\frac{3}{20}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{9}{40}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{3}{10}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{15}{32}$
1.5	$\frac{1}{12}$	$\frac{2}{15}$	$\frac{5}{36}$	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{2}{9}$	$\frac{1}{4}$	$\frac{4}{15}$	$\frac{5}{18}$	$\frac{1}{3}$	$\frac{5}{12}$
2.0	$\frac{1}{16}$	$\frac{1}{10}$	$\frac{5}{48}$	$\frac{1}{8}$	$\frac{3}{20}$	$\frac{1}{6}$	$\frac{3}{16}$	$\frac{1}{5}$	$\frac{5}{24}$	$\frac{1}{4}$	$\frac{5}{16}$
2.5	$\frac{1}{20}$	$\frac{2}{25}$	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{3}{25}$	$\frac{2}{15}$	$\frac{3}{20}$	$\frac{4}{25}$	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{4}$
$2\frac{2}{3}$	$\frac{3}{64}$	$\frac{3}{40}$	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{9}{80}$	$\frac{1}{8}$	$\frac{9}{64}$	$\frac{3}{20}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{15}{64}$

Rotating Standard Constants $= K_s$	Watt-Hour Meter Constants $= K_h$										
	$\frac{2}{3}$	0.75	$\frac{5}{6}$	1.0	1.25	$1\frac{1}{3}$	1.5	$1\frac{2}{3}$	2.0	2.5	$2\frac{2}{3}$
0.05	$\frac{{}^*40}{{}^*3}$	$\frac{15}{1}$	$\frac{50}{3}$	$\frac{20}{1}$	$\frac{25}{1}$	$\frac{80}{3}$	$\frac{30}{1}$	$\frac{100}{3}$	$\frac{40}{1}$	$\frac{50}{1}$	$\frac{160}{3}$
0.10	$\frac{20}{3}$	$\frac{15}{2}$	$\frac{25}{3}$	$\frac{10}{1}$	$\frac{25}{2}$	$\frac{40}{3}$	$\frac{15}{1}$	$\frac{50}{3}$	$\frac{20}{1}$	$\frac{25}{1}$	$\frac{80}{3}$
0.15	$\frac{40}{9}$	$\frac{5}{1}$	$\frac{50}{9}$	$\frac{20}{3}$	$\frac{25}{3}$	$\frac{80}{9}$	$\frac{10}{1}$	$\frac{100}{9}$	$\frac{40}{3}$	$\frac{50}{3}$	$\frac{160}{9}$
0.2	$\frac{10}{3}$	$\frac{15}{4}$	$\frac{25}{6}$	$\frac{5}{1}$	$\frac{25}{4}$	$\frac{20}{3}$	$\frac{15}{2}$	$\frac{25}{3}$	$\frac{10}{1}$	$\frac{25}{2}$	$\frac{40}{3}$
0.25	$\frac{8}{3}$	$\frac{3}{1}$	$\frac{10}{3}$	$\frac{4}{1}$	$\frac{5}{1}$	$\frac{16}{3}$	$\frac{6}{1}$	$\frac{20}{3}$	$\frac{8}{1}$	$\frac{10}{1}$	$\frac{32}{3}$
0.3	$\frac{20}{9}$	$\frac{5}{2}$	$\frac{25}{9}$	$\frac{10}{3}$	$\frac{25}{6}$	$\frac{40}{9}$	$\frac{5}{1}$	$\frac{50}{9}$	$\frac{20}{3}$	$\frac{25}{3}$	$\frac{80}{9}$
$\frac{1}{3}$	$\frac{2}{1}$	$\frac{9}{4}$	$\frac{5}{2}$	$\frac{3}{1}$	$\frac{15}{4}$	$\frac{4}{1}$	$\frac{9}{2}$	$\frac{5}{1}$	$\frac{6}{1}$	$\frac{15}{2}$	$\frac{8}{1}$
0.4	$\frac{5}{3}$	$\frac{15}{8}$	$\frac{25}{12}$	$\frac{5}{2}$	$\frac{25}{8}$	$\frac{10}{3}$	$\frac{15}{4}$	$\frac{25}{6}$	$\frac{5}{1}$	$\frac{25}{4}$	$\frac{20}{3}$
0.5	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{2}{1}$	$\frac{5}{2}$	$\frac{8}{3}$	$\frac{3}{1}$	$\frac{10}{3}$	$\frac{4}{1}$	$\frac{5}{1}$	$\frac{16}{3}$
$\frac{2}{3}$	$\frac{1}{1}$	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{3}{2}$	$\frac{15}{8}$	$\frac{2}{1}$	$\frac{9}{4}$	$\frac{5}{2}$	$\frac{3}{1}$	$\frac{15}{4}$	$\frac{4}{1}$
1.0	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{5}{6}$	$\frac{1}{1}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{2}{1}$	$\frac{5}{2}$	$\frac{8}{3}$
$1\frac{1}{3}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{15}{16}$	$\frac{1}{1}$	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{3}{2}$	$\frac{15}{8}$	$\frac{2}{1}$
1.5	$\frac{4}{9}$	$\frac{1}{2}$	$\frac{5}{9}$	$\frac{2}{3}$	$\frac{5}{6}$	$\frac{8}{9}$	$\frac{1}{1}$	$\frac{10}{9}$	$\frac{4}{3}$	$\frac{5}{3}$	$\frac{16}{9}$
2.0	$\frac{1}{3}$	$\frac{3}{8}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{5}{6}$	$\frac{1}{1}$	$\frac{5}{4}$	$\frac{4}{3}$
2.5	$\frac{4}{15}$	$\frac{3}{10}$	$\frac{1}{3}$	$\frac{2}{5}$	$\frac{1}{2}$	$\frac{8}{15}$	$\frac{3}{5}$	$\frac{2}{3}$	$\frac{4}{5}$	$\frac{1}{1}$	$\frac{16}{15}$
$2\frac{2}{3}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{15}{16}$	$\frac{1}{1}$

Rotating Standard Constants = K_h	Watt-Hour Meter Constants = K_h											
	3.0	3⅓	4.0	5.0	5⅓	6.0	7.5	8.0	10.0	10⅔	12.0	12.5
0.25	*12/*1	40/3	16/1	20/1	64/3	24/1	30/1	32/1	40/1	128/3	48/1	50/1
0.3	10/1	100/9	40/3	50/3	160/9	20/1	25/1	80/3	100/3	320/9	40/1	125/3
⅓	9/1	10/1	12/1	15/1	16/1	18/1	45/2	24/1	30/1	32/1	36/1	75/2
0.4	15/2	25/3	10/1	25/2	40/3	15/1	75/4	20/1	25/1	80/3	30/1	125/4
0.5	6/1	20/3	8/1	10/1	32/3	12/1	15/1	16/1	20/1	64/3	24/1	25/1
⅔	9/2	5/1	6/1	15/2	8/1	9/1	45/4	12/1	15/1	16/1	18/1	75/4
1.0	3/1	10/3	4/1	5/1	16/3	6/1	15/2	8/1	10/1	32/3	12/1	25/2
1⅓	9/4	5/2	3/1	15/4	4/1	9/2	45/8	6/1	15/2	8/1	9/1	75/8
1.5	2/1	20/9	8/3	10/3	32/9	4/1	5/1	16/3	20/3	64/9	8/1	25/3
2.0	3/2	5/3	2/1	5/2	8/3	3/1	15/4	4/1	5/1	16/3	6/1	25/4
2.5	6/5	4/3	8/5	2/1	32/15	12/5	3/1	16/5	4/1	64/15	24/5	5/1
2⅔	9/8	5/4	3/2	15/8	2/1	9/4	45/16	3/1	15/4	4/1	9/2	75/16
3.0	1/1	10/9	4/3	5/3	16/9	2/1	5/2	8/3	10/3	32/9	4/1	25/6
5.0	3/5	2/3	4/5	1/1	16/15	6/5	3/2	8/5	2/1	32/15	12/5	5/2
5⅓	9/16	5/8	3/4	15/16	1/1	9/8	45/32	3/2	15/8	2/1	9/4	75/32
10.0	3/10	1/3	2/5	1/2	8/15	3/5	3/4	4/5	1/1	16/15	6/5	5/4
10⅔	9/32	5/16	3/8	15/32	1/2	9/16	45/64	3/4	15/16	1/1	9/8	75/64

The above tables give the ratio of the revolutions which should be made by the rotating standard to the revolutions made by the watt-hour meter under test when they are connected so as to measure the same energy and their watt-hour constants are related as shown in the table.

The star opposite the upper figures in the horizontal lines indicate the rotating standard revolutions and that opposite the lower figures the revolutions of the watt-hour meter under test.

In the **Philadelphia Electric method of watt-hour meter testing,** the rotating standard is allowed to run continuously and a signal is transmitted to the ear of the tester at each revolution of the moving element of the rotating standard. The number of revolutions as indicated by the signal is then compared directly with the revolutions of the moving element of the meter under test (Fig. 308).

The signal is accomplished by an electrical contact on the moving element of the rotating standard arranged in series with a telephone receiver and a dry battery. A description of these connections will be given later in detail.

This method of applying the rotating standard compares a definite number of complete revolutions of the moving element of the rotating standard to the number of complete and fractional revolutions made by the moving element of the meter under test, during the same period of time; this being the opposite of the potential switch method, where a definite number of revolutions of the moving element of the meter under test are compared to complete and fractional revolutions of the moving element of the rotating standard. In conducting a test, both the rotating standard and the meter under test are started, and while running, a reading may be started at any time by locating the position of a mark on the rotating element of the meter at the instant a signal is received in the head-type telephone. When the meter is correct, the mark will occupy the same relative position at each successive signal (that is, at each revolution of the moving element of the rotating standard) and the total number of revolutions of the moving elements of both rotating standard and meter under test will be equal, providing the test constants of both the rotating standard and meter under test are the same. If the test constants are not the same the number of revolutions of the moving element of the rotating standard and the meter under test will bear a definite ratio to each other, which is determined in the same manner as in other methods employing a rotating standard; that is, by dividing the test constant of the meter under test by the test constant of the rotating standard.

If the meter under test is fast, the relative position of the mark will

advance a certain distance at each successive revolution of the moving element of the rotating standard, and if slow, the mark will drop a certain distance behind the starting point at each revolution of the moving element of the rotating standard. The distance gained, or lost, during a reading may be equal to a whole revolution, or only to a fraction of a revolution, depending upon the error of the meter under test and the time duration of the test. In the latter case, this distance can be determined directly as a fraction of a revolution of the moving element of the meter under test, or determined indirectly by expressing the distance in inches and dividing this number by the circumference (in inches) of the moving element. If desired, a graduated scale can be readily applied

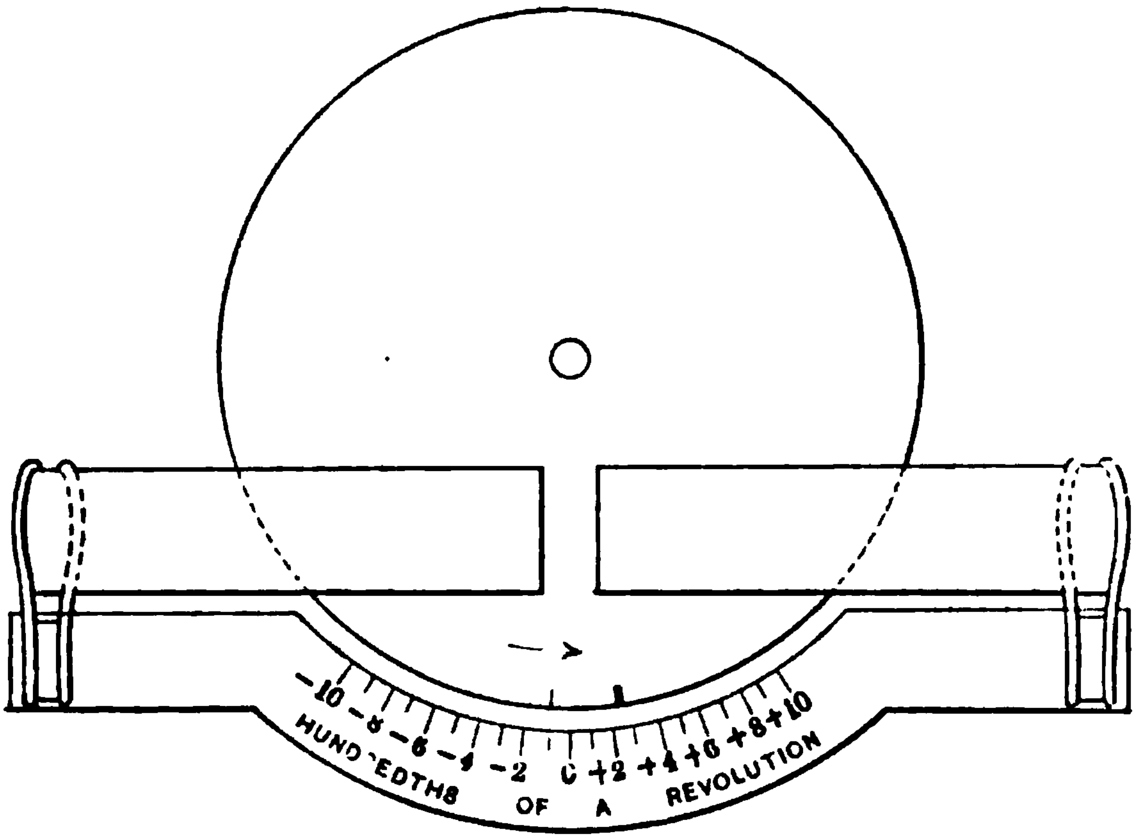


FIG. 309.—Graduated Scale Applied to Watt-hour Meter under Test.

by which the fractional revolution and consequently the percentage error is directly indicated (Fig. 309).

All personal errors are thus reduced to a single determination that can be easily and accurately made. When the moving element of the meter under test is allowed to gain or lose a complete revolution, the possibility of personal error is practically eliminated.

The percentage of accuracy of the meter is determined by dividing the total number of complete and fractional revolutions of the moving element actually made by the meter under test, by the number of complete revolutions it should have made as determined by the rotating standard; that is,

$$\frac{\text{Revolutions meter under test actually made}}{\text{Revolutions meter under test should have made}} \times 100 = \text{Percentage of Accuracy.}$$

By allowing an incorrect meter to gain or lose a complete revolution of the moving element, which is the practice when a meter is more than 2 per cent in error the testing is further simplified and the calculations are rapidly determined mentally. To illustrate, consider a meter 2 per cent in error. The moving element gains, or loses, a complete revolution while the moving element of the rotating standard is making 50 revolutions. The only calculation necessary to determine the percentage of accuracy is $\frac{51}{50} \times 100$, or 102 per cent, if a revolution of the moving element were gained, and $\frac{49}{50} \times 100$, or 98 per cent, if the moving element lost a revolution.

Should the moving element of the meter under test actually gain one complete revolution while the moving element of the rotating standard made 50 revolutions, and should the tester consider that the mark on the moving element of the meter under test did not coincide with the signal until 51 revolutions—that is, should the tester consider that the moving element of the meter under test did not gain a whole revolution until the fifty-first revolution—the error produced in the determination would only be .04 per cent (four one-hundredths of one per cent); or by calculation $\frac{51}{50} \times 100 = 102\%$ and $\frac{52}{51} \times 100 = 101.96\%$, the difference being as stated, .04% (four one-hundredths of one per cent).

Thus it is obvious that the time duration of the test will not necessarily be extended beyond practical limits, for when the meter under test is more than 2 per cent in error, it will naturally require a very short time for the moving element of the meter under test to gain, or lose, a complete revolution.

Since, however, a majority of the meters are found within the limits of plus, or minus, 2 per cent, full load readings are usually about 20 revolutions of their moving element and light load readings not less than 4 revolutions of their moving element. It is apparent, therefore, that the same revolution error at light load represents a greater percentage error than at full load, where it is distributed over a greater number of revolutions. This, however, does not result in greater errors at light load, since the moving element moves at a much lower speed and the determination of a given fractional revolution may be accomplished with greater accuracy.

The calculation required for determining the accuracy of meters found within the usual limits, is ordinarily a simple mental problem, but, as stated, if desired a graduated scale can be readily applied by which the percentage error is directly indicated.

The final adjustment of the meter under test is especially facilitated by the use of the Philadelphia Electric method, since the position of

the starting mark can be observed and the adjustments made until the mark does not change its relative position at each revolution of the moving element of the rotating standard. The revolutions of the moving element of the meter under test and of the standard will then coincide in the proper ratio.

The load device usually employed with the Philadelphia Electric method is described in Chapter IX.

Any rotating standard may be readily adapted for use with the Phila-

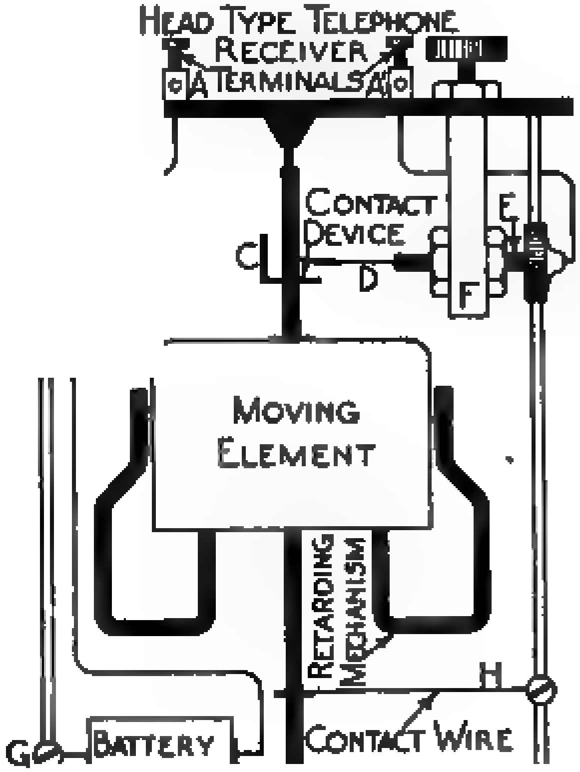


Fig. 310.—Rotating Standard Adapted for Use with the Philadelphia Electric Method

delphia Electric method by equipping it with binding posts and contacts. One of the methods employed is shown diagrammatically, as applied to a rotating standard of the Fort Wayne Electric Works in Fig. 310.

Two small ⅜ inch brass binding posts (A and A_1) are placed on the top plate of the rotating standard for connecting the head-type telephone receiver.

The current for operating the telephone receiver is very small and is obtained from one small dry cell (B), similar to 1 5 volt cells used i

flash lamps, which is usually fastened to the lower part of the frame of the rotating standard. A small discarded dry cell will serve the purpose and will last almost indefinitely without renewal.

A sensitive telephone receiver having a resistance of about 70 ohms should be employed. A convenient type to use is one provided with a head band, and usually known as a head type telephone receiver.

The principal contact making device consists of a small one-pin commutator (*C*) soldered or otherwise fastened to the shaft of the moving element, which makes a wiping contact, at each revolution, with the phosphor-bronze wire brush (*D*). This brush is secured at one end to an adjustable screw (*E*) and this in turn is connected to the binding post (A_1). The adjustable screw turns into an insulated bushing (*F*) made of fiber which is fastened to the top plate of the rotating standard in the manner indicated in the figure.

The brush (*D*) is then adjustable in two horizontal directions, in and out, by means of the adjustable screw (*E*), and on a radius by means of the fiber bushing (*F*).

One side of the dry cell is connected to the other binding post (*A*) and the opposite side of the cell grounded to the frame (*G*.) The shaft of the moving element of the rotating standard usually makes sufficient contact through the gearing, etc., to operate the telephone receiver, but to insure a positive contact, an additional wire brush (*H*) may be grounded to the frame, and allowed to rest against the shaft.

At each revolution of the moving element of the rotating standard, therefore, the battery circuit is completed through the telephone receiver, wiping contacts and frame of the meter, thus transmitting a sharp signal to the ear of the tester.

The commutator pin and contact points on the wire brushes are made of platinum. In making the commutator pin, a $\frac{1}{16}$ inch piece of platinum is used, and it is filed in the form of a V, thus making a knife edge. The contact points on the wire brushes are made of $\frac{1}{16}$ inch platinum wire about $\frac{3}{16}$ of an inch long, the tips of which are somewhat tapered.

In the adjustments of the contact-making devices, the position of the make and break, contact-making, wire brush is varied in position, depending on the uses to which the rotating standard is put. For some purposes a very sharp click in the head-type telephone is desired. Under these conditions the contact-making wire brush is adjusted at right angles to the shaft, and when locked in position the commutator pin very lightly touches the brush at each revolution.

For other purposes it is especially desirable to have a longer con-t. Then adjustments are made so that the commutator pin lightly

touches the contact-making wire brush at a tangent, under which conditions a slightly longer contact is obtained.

After adjustments have been made, the lock nut on the adjustable screw is clamped securely. The additional friction introduced into the mechanism of the rotating standard is practically negligible.

It frequently happens that large capacity, continuous current watt-hour meters are installed to measure the energy consumed in a circuit, the load on which is continually fluctuating to such an extent that it is desirable, with the usual method of testing, to make use of an artificial load when testing the meter. A meter installed on a street railway circuit is an example of this type of installation. With the exception of the Sangamo mercury flotation meter, it is generally not desirable to use the ordinary type of shunt in connection with the continuous current rotating standards, and as rotating standards are not made much in excess of 100 amperes capacity, their use is prohibited for testing watt-hour meters of 1,000 amperes capacity, or over, by the usual methods. In such cases the **Wheatstone bridge method of testing watt-hour meters by means of a rotating standard** is applicable.

If, then a shunt, or rather a number of resistances, are arranged in the form of a Wheatstone bridge, and the rotating standard inserted in one of the legs of the bridge, excellent results may be obtained with a rotating standard of moderate capacity, say 40 or 50 amperes, and using the consumer's load.

In practice, the circuits are arranged as shown in Fig. 311. The apparatus consists primarily of a compound shunt *A*, consisting of two manganin shunts with a common terminal at one end, and individual terminals at the other ends. The larger shunt should be designed to carry the maximum load that the watt-hour meter circuit carries, as for example, 2,000 amperes. The smaller shunt is always designed for the full load capacity of the rotating standard, that is, say 40 amperes.

The resistance element of this compound shunt is preferably made of manganin, as it has a negligible temperature coefficient, and the thermoelectric effect is very small. The full load drops in potential across each leg of the shunt should be not less than 100 millivolts. This compound shunt composes two legs of the bridge, and for the other two legs, recourse is had to the fixed resistance *B*, for the third leg, and the rotating standard and resistances *C* and *D* for the fourth leg. Resistance *B* is preferably made of manganin, and the same in form and capacity as the main shunt in *A*, with a full load drop in potential of approximately 0.40 volts.

The resistance *D* may be a carbon compression rheostat, or any other low resistance, adjustable rheostat, and is used in multiple with *C*, which is a flat strip of any zero temperature coefficient metal, to adjust the resistance of the fourth leg to the bridge to such a value that the galvanometer connected across the terminals of the compound shunt shall read zero. Since the resistances of the two legs of the compound shunt are constant, and have a certain fixed ratio, it is obvious that when the galvanometer reads zero, the current values in the two legs of the shunt also

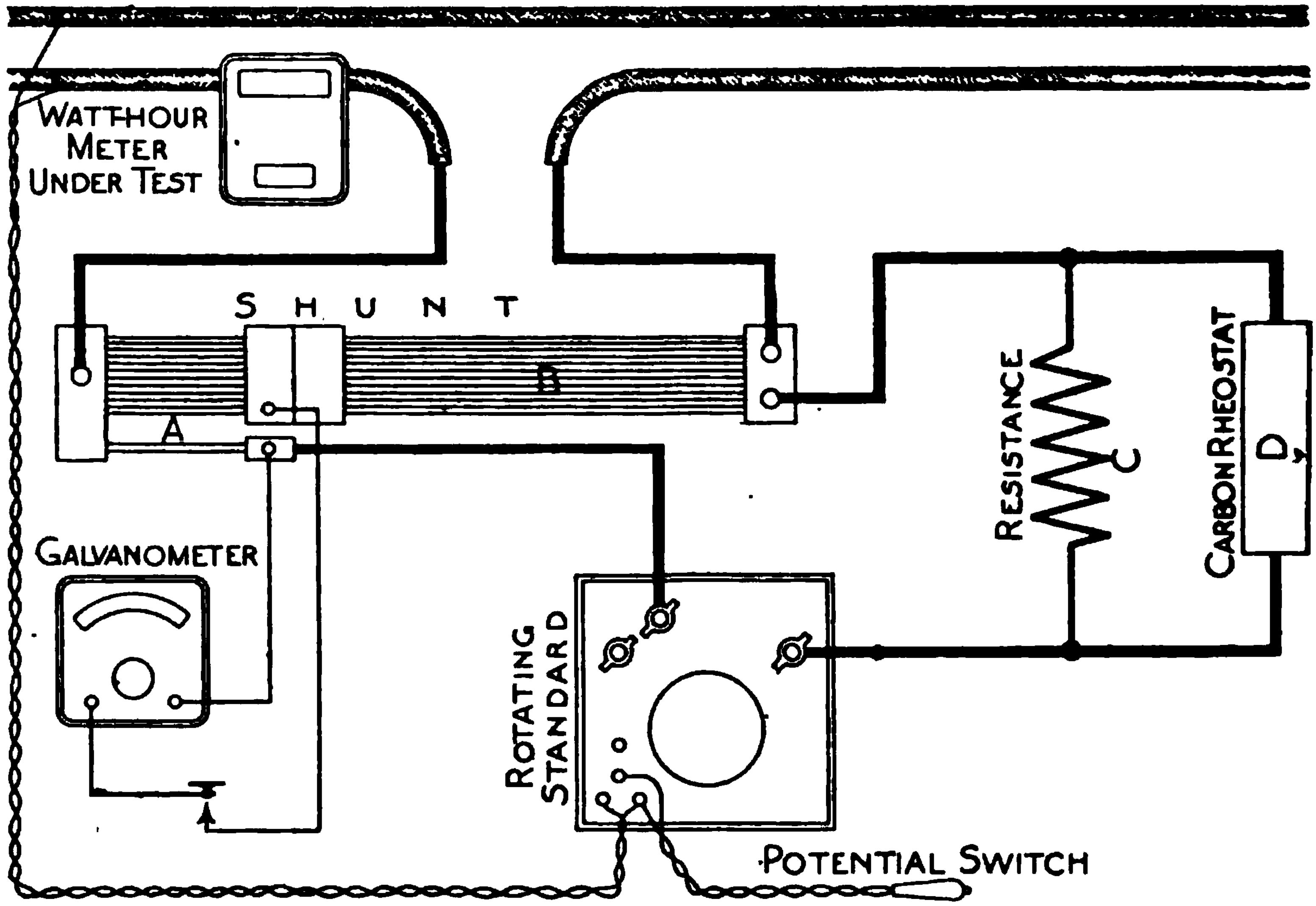


FIG. 311.—Diagram of Connections for the Wheatstone Bridge Method of Watt-hour Meter Testing.

have a certain fixed ratio. As all the current that passes through the smaller of the two shunts also passes through the rotating standard, it is evident that as long as the galvanometer is at zero, measurement is being made of a certain fixed proportion of the total current passing through the watt-hour meter that is under test. For example, if 2,000 amperes in the larger shunt balances 40 amperes in the smaller shunt, the rotating standard will receive $\frac{40}{2040}$ of the total current or one part in 51, and this latter ratio may be used as a multiplying factor for the readings of the rotating standard.

The various resistances of the Wheatstone bridge connections will

remain constant with the exception of the fourth. This, owing to the temperature coefficient of the copper in the fields of the rotating standard, may vary slightly. This, however, is a gradual change and is readily taken care of by the adjustable resistance *D*, hence it does not matter in practice how much the current in the main line may fluctuate, as it is always possible to keep the galvanometer at zero.

It is essential that the current leads to the rotating standard be of low resistance in order to keep the resistance *B* as low as practicable, and they should be from 10 to 15 feet long in order that the rotating standard may be placed so as to avoid stray fields, as much as possible. For the latter reason reversed readings on the rotating standard should always be taken and the results averaged.

The method of **testing watt-hour meters by means of calibrated resistances** is a modification of the indicating instrument method, whereby the value of the resistance used as load in testing is used in connected and utilized in a manner similar to any artificial testing load, on the meter in watts. The apparatus used are a resistance of known and constant value, an indicating voltmeter and a stop watch. Calibrated resistances used for this purpose are described in Chapter IX.

In testing watt-hour meters with a calibrated resistance, the resistance is connected and utilized, in a manner similar to any artificial testing load except that care must be exercised in the voltmeter connections which must not only indicate the voltage applied to the meter but also to the cable terminals of the resistance. As the internal resistance of continuous current voltmeters is very high, the current taken by the voltmeter may be ignored for all loads in excess of one ampere; for loads less than one ampere, the voltmeter should either be connected to the load side of the watt-hour meter or the current taken by the voltmeter allowed for. For loads in excess of one ampere the drop in the watt-hour meter fields enters as a factor, depending upon the point of connection of the watt-hour meter potential circuit. If its potential circuit is connected to the load side of the watt-hour meter, the voltmeter should also be connected at this point, and then no error will be introduced. If the potential circuit is connected to the service side of the watt-hour meter, and the voltmeter is also connected at that point, allowance should be made for the drop in the watt-hour meter fields when computing the wattage consumed by the resistances.

For the purpose of facilitating the use of the calibrated resistance, a set of tables may be compiled as follows, Figs. 312 and 313. First, a table showing the watts for each half volt for each of the different combinations in the calibrated resistance, that may be used. This table is only used when watt-hour meters are tested for which no special table has

been compiled. Second, a table for each of the various test constants that may be met with. These tables should show for each half volt correct time in seconds for a given number of revolutions. The table may also show if desired the load in amperes, or watts. For example, with a meter having a watt-hour constant of 0.5, and the voltage being 110.5, the meter should make 10 revolutions in 32.4 seconds with one 22 ohm unit connected, and one revolution in 34.5 seconds with one 234 ohm unit. It should be noted that in computing percentage of accuracy the correct

CALIBRATION CARD

(10% LOAD=.5 AMP.) K=.2

VOLTS	FULL LOAD AMPS	FULL LOAD 20 REVS	10% LOAD 2 REVS
105	4.77 4.80	35.9 35.6	45.8 45.1
106	4.82 4.84	35.2 34.9	45.0 44.6
107	4.86 4.89	34.6 34.3	44.1 43.7
108	4.91 4.93	34.0 33.6	43.5 42.9
109	4.95 4.98	33.3 33.0	42.5 42.2
110	5.00 5.02	32.7 32.4	41.8 41.4
111	5.05 5.07	32.1 31.9	41.0 40.7
112	5.09 5.11	31.6 31.3	40.3 39.9
113	5.14 5.16	31.0 30.7	39.6 39.2
114	5.18 5.20	30.5 30.2	38.9 38.6
115	5.23 5.25	29.9 29.7	38.2 37.9
116	5.27 5.30	29.4 29.2	37.6 37.2
117	5.32 5.34	28.9 28.7	36.9 36.6
118	5.36 5.39	28.4 28.2	36.1 36.0
119	5.41 5.43	28.0 27.7	35.7 35.4
120	5.45 5.48	27.5 27.3	35.1 34.8

CALIBRATION CARD

(10% LOAD=.5 AMP.) K=.5

VOLTS	FULL LOAD AMPS	FULL LOAD 10 REVS	10% LOAD 1 REV.
105	4.77 4.80	35.9 35.6	38.2 37.8
106	4.82 4.84	35.2 34.9	37.5 37.1
107	4.86 4.89	34.6 34.3	36.8 36.4
108	4.91 4.93	34.0 33.6	36.1 35.8
109	4.95 4.98	33.3 33.0	35.5 35.1
110	5.00 5.02	32.7 32.4	34.8 34.5
111	5.05 5.07	32.1 31.9	34.2 33.9
112	5.09 5.11	31.6 31.3	23.6 33.3
113	5.14 5.16	31.0 30.7	33.0 32.7
114	5.18 5.20	30.5 30.2	32.4 32.1
115	5.23 5.25	29.9 29.7	31.9 31.6
116	5.27 5.30	29.4 29.2	31.3 31.0
117	5.32 5.34	28.9 28.7	30.8 30.5
118	5.36 5.39	28.4 28.2	30.3 30.0
119	5.41 5.43	28.0 27.7	29.7 29.5
120	5.45 5.48	27.5 27.3	29.3 29.0

FIG. 312.—Tables for Use with Calibrated Resistance Method of Watt-hour Meter Testing.

STANDARD BOX.

VOLTS	WATTS 22 OHMS 1 UNIT	WATTS 22 OHMS 2 UNITS	WATTS 234 OHMS 1 UNIT	WATTS 234 OHMS 2 UNITS
105	501 506	1002 1012	47.1 47.6	94.2 95.1
106	511 516	1021 1031	48.0 48.5	96.0 96.9
107	521 525	1041 1051	48.9 49.4	97.9 98.8
108	530 535	1060 1070	49.8 50.3	99.7 100.6
109	540 545	1080 1090	50.8 51.2	101.6 102.5
110	550 555	1100 1110	51.7 52.2	103.4 104.4
111	560 565	1120 1130	52.7 53.1	105.3 106.3
112	570 575	1140 1150	53.6 54.1	107.2 108.2
113	581 586	1161 1171	54.6 55.1	109.2 110.1
114	591 596	1181 1192	55.6 56.0	111.1 112.1
115	601 606	1202 1212	56.5 57.0	113.0 114.0
116	612 617	1223 1234	57.5 58.0	115.0 116.0
117	622 628	1245 1255	58.5 59.0	117.0 118.0
118	633 638	1266 1276	59.5 60.0	119.0 120.0
119	644 649	1287 1298	60.5 61.0	121.0 122.0
120	655 660	1309 1320	61.5 62.1	123.1 124.1

FIG. 313.—Table of Watts Load at Various Voltages.

time should be divided by the actual time, as the watts recorded by the meter are inversely proportional to the time in seconds.

The preferable method of calibrating a resistance is to apply to its terminals, the full line voltage for which the resistance is designed and measure the current with a millivoltmeter and shunt for the applied voltage at the cable terminals. In practice it will be found necessary to do this at only one point as, for example, 110 volts, and any change in the resistance will be readily detected by the millivoltmeter readings. For the purpose of obtaining the correct, or desired voltage, a rheostat of small range placed in series with the load box is advantageous. All connections should be so made that the voltmeter current is measured by the millivoltmeter and allowance made for the same.

The adjustments to correct errors in the full load units may be made by a slider and for the small load units by the addition of small resistance buttons. The resistances if well designed, are, however, very stable and seldom need adjustment, though a weekly check should always be made.

The earliest forms of calibrated resistances consisted of banks of seasoned and calibrated incandescent lamps which were subject to disadvantages arising from their bulk, liability to breakage, and variations in resistance due to overload.

In the latest forms of calibrated resistances, resistance units composed of zero temperature coefficient metal, capable of carrying their rated watts continuously without change in resistance, and unaffected by repeated heating and cooling, are employed. The units are constructed to be immune from easy accidental damage and are mounted in a protecting box or frame with suitable switches for connecting the various ranges in circuit. The switches must have a negligible contact resistance.

Where it is desired to avoid the use of corrections, a convenient and reliable means of adjusting the resistances should be provided, in which case the resistances will be readjusted whenever found in error in the periodic checks.

The connecting leads are a part of the calibrated resistance, and should be maintained in perfect condition.

The calibrated resistance method can be used on continuous and alternating current systems. For alternating current tests, the resistances should be non-inductively wound.

The accuracy with which the load is determined is, assuming the resistance to be correct, dependent only on the accuracy of the voltmeter, but it should be borne in mind that a given percentage error in calibrating or in reading the voltmeter affects both the voltage and the current, and therefore produces double the percentage error in the watts.

Personal errors affect the results obtained with different standards in somewhat different ways and to somewhat different extents. With practice, the personal error of an observer tends to become constant, so that if it is large it can be determined and corrected for. In some important cases, as for example, timing a meter with a stop watch, a constant personal error may annul itself and not enter into the final result.

CHAPTER IX

AUXILIARY EQUIPMENT FOR TESTING CONSUMERS' WATT-HOUR METERS

CHAPTER IX

Auxiliary Equipment for Testing Consumers' Watt-hour Meters

Suitable **equipment for testing watt-hour meters** in addition to the standards should be provided in order that the work may be performed in the most accurate and efficient manner possible. For testing meters in service this apparatus must be portable and may differ in type from that used in the shop, which has already been described. It is advisable that central station companies provide all equipment in order that it may be of a character best suited for the different lines of work. The company should take pains to maintain the equipment in good condition, as a well-kept and neat-appearing outfit is conducive to better work on the part of the tester and will increase the confidence of the consumer whose meter is being tested in the accuracy and carefulness of the company's methods. It should be the duty of the foreman to see that each tester's equipment is kept intact and up to the grade established by the management, and the duty of the tester to report faults and deficiencies which may develop in his equipment.

Although a meter can be tested on the consumer's load, and in some cases this may be desirable, the use of **portable loading devices** is advantageous in that it furnishes a ready means of testing the meter at various loads and also prevents annoyance to the consumer. The following means are available for obtaining loads for testing:

The consumer's load.
A portable lamp bank.
A load box constructed of suitable low temperature coefficient resistance material.
A water rheostat.
A portable storage battery.
A step-down transformer from the secondary circuit of which the testing current is taken.

Lamp banks are operated at the line voltage and can be made up of a number of flat base lamp sockets securely fastened to a suitable carrying frame, generally made of wood in the shape of a rectangular

box with open sides, the inside being covered with asbestos. The sockets are placed inside, as this arrangement affords protection to the lamps during transportation. The lamps are arranged in certain groups, and switches are provided to cut in any number of lamps in steps of one, from a single lamp to the full capacity of the bank. Owing to its large size and the excessive breakage of lamps, the

FIG. 314.—Watt-hour Meter Testing Rheostat. Closed. General Electric Company.

FIG. 315.—Watt-hour Meter Testing Rheostat. Open General Electric Company.

lamp bank, formerly much used as a portable unit, has been largely superseded by the load box or meter testing rheostat.

General Electric watt-hour meter testing rheostats (Figs. 314 and 315) furnish a very convenient load for meter testing. The switches and resistances are designed to give loads varying from one-half of an ampere to the full load rating of the rheostats, in half-ampere steps. Each switch is marked with the value of the load which it controls. Suitable binding posts are provided into which the line wires are inserted and fastened by set screws. The resistance units furnished with the 15 ampere rheostat are cylindrical in shape and

are securely fastened to the base of the box and reinforced by a small brass rod which passes through their center and prevents buckling due to extreme heat. Flat units made of the same material are furnished with the 30 ampere rheostat and are made in this form in order to economize space.

The resistance metal is non-corrosive and has a very low temperature coefficient. It is wound on a fireproof body and the complete unit is covered with a protecting compound which will not crack

FIG. 316. — Watt-hour Meter Testing Rheostat and Tool Box of the United Electric Light and Power Company.

and peel off, nor will it melt and run like enamel, but will become harder when subjected to high temperatures. As the units have a negligible temperature coefficient, the load remains steady as the resistance heats up, thus permitting the rheostat to be used with satisfactory results in testing meters when portable indicating instruments are used. The inductance of the units is also negligible, therefore the device can be used interchangeably on continuous or alternating current circuits. They are made in two sizes: a 15 ampere, 110 volt to 120 volt rheostat, which is 14 by 7½ by 1¾ inches in size and weighs 7 pounds; and a 30 ampere, 110 volt to 120 volt

rheostat which is 12⅛ by 7⅛ by 4⅛ inches in size and weighs 14 pounds.

These meter testing rheostats are manufactured by the General Electric Company, of Schenectady, N. Y.

The load box of The United Electric Light & Power Company, of New York (Fig. 316), has a capacity of 2,300 watts at 230 volts in steps of ½, 1, 1, 1, 1, 3 and 3 amperes, and is a modification of the standard General Electric load box. The case is made of aluminum No. 16 gauge. A tool box 4¼ by 7¼ by 12 inches, also of aluminum, is arranged to be readily attached to the box and forms one of the covers of it. The method of attachment consists of a projecting lip

FIG. 317.—Watt-hour Meter Testing Rheostats. Ward Leonard Company.

on the box which engages in a slot at the bottom of the resistance box. A hook at the top of the box holds it firmly to the tool case. The dimensions of the box are 7¾ by 8¾ by 12¾ inches and it weighs 20½ pounds. The handle of the tool case is arranged to engage with hooks on the handle of the load box, and this brings the handle over the center of gravity when the two are carried together. The simplicity of the fastening and general arrangement is such that the load box can be set up ready for connections and the tool box opened in a very short space of time.

Ward Leonard watt-hour meter testing rheostats (Fig. 317), are operated at the line voltage, and as they are non-inductive, they can be used interchangeably on continuous or alternating current circuits. The resistance units are fireproof, strong, light, and well protected by a metal screen which affords ample heat radiation.

The resistance elements are built up of standard Ward Leonard enameled resistance units which are fastened to the face plate. The face plate and resistance units can be taken out easily, and the different units replaced in case of injury. The various ampere steps or combinations are obtained by paralleling the several resistance combinations by suitable switches.

Stock rheostats are made in the following sizes:

Amperes	Volts	Steps or Ampere Divisions	Dimensions	Approx. Weight
5	120	¼ Amp.	5 × 5 × 9	8
10	120	½ "	5 × 8 × 9	10
15	120	½ "	5 × 10 × 9	11
20	110	½ "	5 × 12 × 9	13
23.5	110	½ "	5 × 14 × 9	14
5	220	¼ "	5 × 8 × 9	10
10	220	½ "	5 × 12 × 9	13
15	220	½ "	5 × 20 × 9	18
20	220	½ "	5 × 24 × 9	22

Combination 110 volt and 220 volt rheostats giving 24 amperes in ½ ampere steps on 110 volts, and 12 amperes in ¼ ampere steps on 220 volts are also carried in stock. These are 7 by 15 by 9 inches and weigh approximately 16 pounds.

These meter testing rheostats are manufactured by the Ward Leonard Electric Company, of Bronxville, N. Y.

Cutler-Hammer watt-hour meter testing rheostats (Fig. 318) are operated at the line voltage, and as they are non-inductive, they can be used interchangeably on continuous or alternating current circuits.

They are made up of flat fireproof units, the whole being surrounded by a metal-protecting screen which also affords heat radiation. Suitable switches are provided for placing the various resistance units in circuit, and each switch is marked with the value of the load which it controls. The plate on which the switches are mounted is made of asbestos lumber. This permits using the rheostat at high temperatures without cracking. It is provided with folding feet, one of which may be turned up and used as a carrying handle. The rheostat must never be used except when in a horizontal position, which permits free radiation through the units. Current should be switched off between observations, but if due to high voltage or long tests, the units should become dull red, no immediate damage is to be expected.

The rheostats are manufactured by the Cutler-Hammer Manufac-

turing Company, of Milwaukee, Wis., and are listed in the following sizes:

DIMENSIONS

Volts	Min. Amp.	Max. Amp.	Amp. Steps	Number Switches	Folded Top Area	Folded Height	Open Top Area	Open Height	Approximate Weight
115	.5	7.5	.5	5	5x7	9	7x8	7	8 lbs.
115	.5	20	.5	6	5x11	15	10x11	9	14 lbs.
115 and 230	.25 .25	20 10	.25 .25	6	"	"	"	"	"
600	.5	4	.5	4	"	"	"	"	"
115	.5	50	.5	8	5x13	19	18x13	19	30 lbs.
115 and 230	.25 .25	50 25	.25 .25	8	"	"	"	"	"
600	.5	10	.5	6	"	"	"	"	"
230	.5	25	.25	7	"	"	"	"	"
115 and	.25	40	.25	7	"	"	"	"	"
230	.25	20	.25	7	"	"	"	"	26 lbs.
115	.5	40	.5	7	"	"	"	"	"

The load box of the Philadelphia Electric Company (Fig. 319) has a capacity of 2,100 watts, and is arranged for use on 110 or 220 volt circuits. The units are non-inductive and they may be used interchangeably on continuous or alternating current circuits. In place of binding posts, special spring contacts are used in conjunction with a plug terminal similar to a cartridge fuse, thus minimizing the possibility of a short circuit. The plugs serve as terminals to which the extra flexible leads are connected. The box is provided with spring contacts on each end for two plug terminals. When these terminals are inserted in the contacts at one end, the box is adapted for use on a 110 volt circuit, and when inserted at the other end, for a 220

FIG. 318.—Watt-hour Meter Testing Rheostat. Cutler-Hammer Manufacturing Company.

volt circuit. The type C and D General Electric Company resistance units are used; they are light weight and tubular and are of the following capacities:

FIG. 319.—Watt-hour Meter Testing Rheostat and Tool Box used by the Philadelphia Electric Company. Eastern Specialty Company.

Two 50 watt, two 100 watt and four 450 watt units.

They are connected to four small multipoint switches so that combinations desired may be readily obtained. The units are so connected that the switches may be set for light loads and heavy loads independently. On the arbor of each switch is mounted a pointer that indicates on a scale marked on the end plate. The connections of the box may be arranged by means of these switches, so as to give the proper loads for testing any meter within the range of the capacity of the box. This may be done simply by moving the multipoint switches, so that the pointers on the switches indicate the desired value. The flexible leads used to connect the box to the circuit consist of separate cables for light and heavy loads. The load box may be connected in circuit with the rotating standard, or instrument shunt, so that the light load and heavy load will be on different ranges of the standard. The frame is constructed of stiff aluminum plates, between which are mounted the resistance units; the whole being held together by thin-walled enameled steel tubes securely bolted to the end plates. On the end plates are mounted the switches and connecting contacts. The load box is provided with a detachable tool case, 12 by 6 by 2¾ inches, which is attached to the frame with small split hinges and trunk clamps. When in use the tool case is detached and the load box is placed in a horizontal position to facilitate heat radiation. The load box may be used with or without the tool case, as desired. The weight without tool case is 7 pounds and 7 ounces, and with tool case is 8 pounds and 10 ounces. The size is 12 by 9 by 6 inches without tool case, and with tool case the over-all dimensions are 14½ by 12 by 9 inches. The weight complete with a full set of tools is from 12 to 15 pounds.

This load box can be obtained from the Eastern Specialty Company, of Philadelphia, Pa.

The calibrated resistance used by the Edison Electric Illuminating Company, Boston, Mass., is described below (Fig. 320):

The very low temperature coefficient feature of special resistance units which permits their carrying their rated load continuously without appreciable change in the resistance, or effect due to repeated heating or cooling, makes it possible to use them as a calibrated resistance. The calibrated resistance that is used as the load consists of a number of units combined in one frame or carrier. The frame is constructed of hard black fiber pieces, between which are mounted the resistance units, the whole being held together by brass rods bolted to the end pieces. These units may be constructed of bare resistance metal or preferably of some of the commercial

resistance units now on the market. In either case the resistance itself must be of zero temperature coefficient, and, if it is to be used on alternating current, must be so mounted as to have a negligible inductance.

FIG. 320.—Calibrated Resistance used by the Edison Electric Illuminating Company of Boston. Lundin Electric Manufacturing Company.

This resistance consists of four units, two having a resistance of approximately 220 ohms each and two a resistance of 22 ohms each By means of suitable switches these units may be connected in multiple or series, and the following loads obtained:

110 volts Load in watts	220 volts Load in watts
25	100
50	1,000
100	
250	
500	
1,000	

The 22 ohm unit is composed of two resistance tubes of approximately 10 ohms each, with an additional resistance of bare wire inserted in series with them, to make up the 22 ohms, and also to act as a means of adjustment.

The 220 ohm unit is composed of one resistance tube and the necessary adjustment is made by the addition of a disk of the necessary resistance value. While it is not necessary that the units should be of exactly 22 and 220 ohms resistance, they should be made to conform to some standard for two principal reasons.

First: Where more than one resistance is used there will be no chance of error, due to the tester using the watt values applying to some other resistance.

Second: Only one set of calibrating cards is necessary for all the resistances (Fig. 312).

The switch contacts are of so low a resistance compared with the rest of the circuit that any errors due to poor contacts are negligible. The switches should be mechanically rugged, however, as being exposed, they are necessarily subjected to more or less abuse.

The two cables connecting the resistance box to the watt-hour meter under test should be made of not less than 65 strands of No. 30 B. & S. gauge copper wire, as continual use breaks some of the strands, and while this does not seriously affect the carrying capacity of the cable, the resultant change in the resistance on a cable of a smaller number of strands may cause an appreciable error.

This load box can be obtained from the Lundin Electric Manufacturing Company, Boston, Mass., and is 9½ by 7 by 5¾ inches in size and weighs about 4½ pounds.

The load resistance and case used by the Edison Electric Illuminating Company of Boston (Fig. 321) has a capacity of 60 amperes at 113 volts. The weight of the four sections of resistance is 3.5 pounds; the weight

of case alone is 2¾ pounds; the combined weight is 6¼ pounds and the dimensions of the case are 12¾ by 12¼ by 13⅓ inches.

Water rheostats are operated at the line voltage, and have been used successfully for obtaining large currents for testing watt-hour meters. They may be used interchangeably on continuous or alternating current

FIG. 321.—Watt-hour Meter Testing Rheostat used by the Edison Electric Illuminating Company of Boston

circuits. A water rheostat giving current up to 150 amperes can be made with a wooden tank having a receptacle on one side, which supports a half-inch brass goose-necked tube carrying a reel for raising, or lowering, the plates into the tank to obtain different loads. The plates are suspended at the end of a cord which passes through the tube and is fastened to the reel. The plates can be removed and the tube taken down, and

these, with the leads, et cetera, can be placed inside the tank, thus making it very convenient for transportation. The tank used for this rheostat is 18 by 14¼ by 8¼ inches, and with the plates and supporting rod weighs 26⅛ pounds. The plates are separated about one-half inch by means of hard rubber or fiber bushings and are held together by rubber fittings or bolts. Lead or steel sheets can be used in making up the plates; however, the weight will be less

FIG. 322.—Water Rheostat used by the Commonwealth Edison Company

when steel is used, for when they are made of lead, heavier stock is required in order to give the plates sufficient stiffness. This same type of rheostat has been made in a larger size to give currents up to 500 amperes for a period of a minute (Fig 322).

Another form of water rheostat consists of an ordinary fiber wash-tub (Fig 323), in which the plates are mounted on a rod passing through it in such a manner that the distance between them can be regulated by means of a screw adjustment to obtain different loads. This rheostat has a capacity of 250 amperes. It has sufficient room for storing leads, special connectors, et cetera, during transpor-

tation. The cover is provided with legs, and when removed it can be used as a table or bench for instruments. Water with a little common salt is the solution used with these rheostats, and after the completion of the test, it is thrown out and the rheostat filled again at the next stop. It is well to have these rheostats equipped with fuse protection, and suitable terminals provided for the line wires.

In the use of water rheostats care should be exercised to see that an abnormal load is not put upon the consumer's service fuses, and it is advisable in many cases to reinforce these temporarily during the test.

The **storage battery** is a very economical loading device for testing large capacity watt-hour meters, in that the testing may be done with the expenditure of very little energy, and it has the additional advantage that there is no overloading the mains and fuses, so that the possibility of interrupting the consumer's service is lessened. The ordinary types of lead batteries (Fig. 324) may be used for this work, but the new Edison battery is better adapted for use as a portable unit.

FIG. 323.—Water Rheostat used by the Philadelphia Electric Company

The Edison storage battery (Fig. 325) has an alkaline electrolyte instead of acid, and is constructed of nickel-plated steel throughout. The retaining can is made of sheet steel welded at the seams, thus reducing to a minimum the possibility of breakage or leakage due to severe vibration. The battery is light in weight and very durable. It will stand a great amount of work, and it is not subject to injury from vibration, overcharging, and high-rate discharging For an

Edison battery charged and discharged daily, the care chiefly consists in adding pure distilled water once or twice a week, and keeping the outside of the cell clean and dry, and renewing the electrolyte after eight or ten months. When examining these cells an open flame should never be brought near the vent as the gases discharged are explosive. The battery can be left in either a charged, or discharged, condition, without any deterioration whatever. The A-4 or B-4 batteries

FIG 324. Storage Battery for Watt-hour Meter Testing. Lead Type.

put up in pairs in a two-cell tray make a very convenient portable loading device, the former giving current up to 150 amperes and the latter giving current up to 75 amperes. The batteries should be kept in circuit during the test period only. The storage battery is particularly adapted to the testing of watt-hour meters on 500 volt circuits, it being impractical to use meter testing rheostats for obtaining heavy loads on circuits of this voltage.

The following types are listed by the Edison Storage Battery Company, of Orange, N. J.

TABLE OF DATA

	B-2	B-4	B-5	A-4	A-6	A-8	A-10	A-12
Normal Ampere Hour Output....	40	80	120	150	225	300	375	450
Average discharge voltage per cell..........................	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Rate of charge ampere for 7 hours.	8	16	24	30	45	60	75	90
Normal rate of discharge amperes.	8	16	24	30	45	60	75	90
Weight in lbs. of cells complete...	4.6	7.35	10.5	13.5	19.2	27.5	34.0	40.8
Average weight per cell of battery assembled in trays............	5.55	8.68	11.8	15.0	21.0	30.3	37.5	45.0
Overall Dimensions in Inches:								
Width of standard tray.........	6½	6½	6½	6⅛	6⅛	6⅛	7¾	9
Extreme overall height of cell assembled..................	9⅝	9⅝	9⅝	14 5/16	14 5/16	14⅞	14⅞	15½
Length of trays 2 cell tray....	5	7¼	9½	7⅞	10	12¾	13¾	13¾
3 " "	6⅞	10⅜	13¾	10	14¼	18⅜	19¾	19¾
4 " "	8¾	13½	18	14	18½	24	25¾	25¾
5 " "	10¾	16⅝	22¼	17⅛	22¾	29⅝	31¾	31¾
6 " "	12⅝	19¾	26½	20¼	27	35¼		
7 " "	14⅝	22⅞	30¾	23⅜	31¼			
8 " "	16½	26	35	26½	35½			
9 " "	18½	29⅛		29⅝				
10 " "	20⅜	32¼		32¾				
11 " "	22⅜							
12 " "	24¼							

The battery can be used with good results under different conditions of temperature. A convenient form of regulating resistance or

Fig. 425. Storage Cell for Watt-hour Meter Testing used by the Potomac Electric Company. Edison Type.

rheostat should be provided, and one can be made up of a number of suitable, thin carbon plates, so arranged in a holding frame that the turning of a small hand wheel will press the plates together.

changing the resistance of the circuit so that any desired amount of current can be obtained up to the capacity of the battery (Fig 326). The batteries are supplied with a carrying tray and the carbon rheostats are sometimes mounted on the side of this tray (Fig. 327). Another method of controlling the current is to arrange a small board with resistance wire zigzagged across it, having binding posts at each bend, so that by

FIG 326.—Carbon Rheostat used with Storage Battery for Watt-hour Meter Testing, by the Philadelphia Electric Company

changing the connections to different binding posts different values of current may be obtained.

By **the use of special step-down transformers**, it is possible to obtain an artificial load of large amperage for which the energy required is comparatively small. This method is especially adapted to the testing of large capacity alternating current watt-hour meters. When transformers are used, the power-factor in the testing circuit is likely to be less than unity, and a thorough investigation should be made as to their phase displacement under working conditions.

as such transformers, unless properly designed, are liable to introduce errors into the results. However, in a watt-hour meter which is correctly lagged the error introduced by a moderate phase displacement will be negligible.

Transformers of this type have been placed on the market by several manufacturers or they may be made by the central station companies.

FIG. 327.—Storage Battery of Two Cells (Edison Type) with Carbon Rheostat Attached, used for Watt-hour Meter Testing by the Commonwealth Edison Company

FIG. 328.—Phantom Load, Type A, for Watt-hour Meter Testing. The States Company.

The States Company's phantom load, type A (Fig. 328) consists of a potential transformer having its low-voltage secondary provided with taps and a resistance so arranged that any current from zero to the full capacity of transformers may be obtained at will to supply the load current of watt-hour meter and rotating standard used in test. It is especially convenient for use with large capacity meters. The high-tension winding of the transformer is connected directly across the line on which the watt-hour meter is installed, and consequently the core magnetization is constant at all loads. This

arrangement also make it possible to use the same apparatus on different voltages by winding the high-tension side in sections for multiple or series connection. The resistance is an alloy grid and is connected across a portion of the low-tension winding permanently. The contact arm of the rheostat is moved by means of a convenient hardwood knob. This arrangement makes it possible to change the value of the load current from zero to maximum very easily. Adjustments are made readily and quickly and no change of meter connections is necessary during test. The apertures in the side of the instrument are provided for the insertion of a bayonet plug. Inserting the plug in various apertures connects to points in the low-tension winding giving large adjustments of load current, small adjustments being made with the rheostat. This device is listed in capacities from 50 amperes to 150 amperes at 110, 220, 440 and 550 volts. The small capacity transformers for 60 cycle current are 5½ by 5½ by 7 inches in size and weigh 10½ pounds. The large capacity transformers built for lower frequencies are 8 by 6 by 7½ inches in size and weigh 21 pounds. Other capacities are listed which are intermediate in size and weight.

The type B phantom load consists of a transformer, the high-tension winding of which is connected across the full line voltage, the load current being taken from a low-tension winding. Control of load current is by means of resistances and selective switches, the resistances being connected in multiple in the low-tension circuit. By this arrangement the load current may be predetermined, and by closing different switches different values of current may be obtained. The transformer and resistances are mounted in a light and strong metal box, with weight properly distributed for carrying. The switches are mounted on the inside of the hinged cover in such a way that they are in a very convenient position when in use; but are completely protected when the box is closed for carrying. The small type B devices of 5 ampere and 7½ ampere capacity are very convenient for testing secondary watt-hour meters used with current and voltage transformers where the necessary low voltage current is not available for making the test in the usual way. By using this device, connecting to the meter voltage transformer, full load test may be made on the watt-hour meter with a total load on the transformer of approximately 60 watts. All sizes have switches arranged to control load current in ¼ ampere steps, from ¼ ampere to full rating of device. This device is listed in capacities from 5 amperes to 150 amperes at 110, 220, 440 and 550 volts. The small capacity transformers for 60 cycle current are 6½ by 5 by 3 inches

in size and weigh 4 pounds The larger capacity transformers increase in size up to 18 by 9 by 10 inches and a weight of 45 pounds (Fig. 329).

The type C phantom load consists of a transformer, the high-tension winding of which is connected directly to the line on which the watt-hour meter is installed, the load current being taken from the low-voltage winding. The load currrent is controlled by multiple resistances on the low-tension side, these resistances being connected or disconnected by means of suitable switches. The resistances are flexible stranded wires which are assembled in a cable specially manufactured for this apparatus. This cable also forms the leads necessary for connecting up instruments during test. This apparatus is furnished in a leather carrying case having sufficient room for tools and leads. It is made in 33½ ampere capacity only, at 110, 220, 440 and 550 volts The current steps are ½, 1, 2, 5, 10 and 15 amperes (Fig. 330) These devices are put on the market by the States Company, of Syracuse, N. Y.

FIG 329.—Phantom Load, Type B, for Watt-hour Meter Testing The States Company.

The Rollinson watt-hour meter testing set is for alternating current testing only. By using a transformer of special design and controlling the same by using absolutely non-inductive resistance units, no appreciable errors of any kind are introduced.

All connecting terminals and plug switches are properly marked. Small terminals are provided for the potential circuits; two heavy ones for the current circuits. Provision has been made by furnishing two terminals for inductive load. By use of but four snap switches and an adjustable rheostat, any desired load in watts, from zero to maximum, can be readily obtained.

This transformer is put on the market by the Mohawk Electric Company, Albany, N. Y., and is listed in capacities from 5 amperes to 200 amperes at 110; 220 and 440 volts It is 14 by 9 by 6¾ inches in size and weighs 16 pounds

Fig 330.—Phantom Load, Type C, for Watt-hour Meter Testing The States Company

The low-voltage transformer used by The United Electric Light and Power Company, New York, is a shunt transformer with a low-voltage winding. The high-tension side is wound for a maximum of 220 volts and has taps brought out at points which give approximately 100, 75, 50 and 25 per cent of the full voltage of the low-tension side. In order to protect the instruments from overload, a preventative resistance is placed in the low-tension circuit. This resistance is of a material having a low temperature coefficient, and means are provided to vary the amount in the circuit. The range is sufficient to bridge the steps in the high-tension winding, thus giving any desired steps in the amount of current. In this particular apparatus the low-tension winding consists of three turns. A tap is brought out at the first turn, giving one-third of the full voltage

the winding. Objection might be made to the fact that the high-tension winding is an auto-transformer, and when the 100-per-cent tap is used a high potential is established across the entire winding. If the coil is properly insulated and the contacts shielded no trouble will be experienced. This transformer has sufficient capacity for testing 150 ampere watt-hour meters, and may be used without introducing errors due to low power-factor. This device is mounted in a box 7¾ by 7¾ by 7 inches and the complete apparatus weighs 15¼ pounds.

FIG. 331 —Transformer Type of Artificial Load for Watt-hour Meter Testing. Eastern Specialty Company

The Universal Load Box (Fig. 331) is a device of the transformer type and has been designed to meet the various requirements of watt-hour meter testing.

The Type "H" load box is suitable for testing both 110 and 220 volt watt-hour meters of from 3 amperes to 75 amperes capacity, two-, three-, or four-wire; being equally suitable for watt-hour meters of either the low or high capacity.

The high-tension side is wound in sections to obtain series, and rallel combinations for 110 volt and 220 volt circuits. A rotating

type, indicating switch is provided, and the high-tension side is thus adapted for circuits of either voltage. A pointer on the switch arbor indicates the voltage for which the load box is set. The high-tension winding is connected directly across the line. The entire winding is in circuit at all times when testing, thus producing a constant core loss. The maximum wattage consumed at full load is 60 watts.

The low-tension winding is separated into two independent ranges, one having a capacity of 5 amperes and the other a full load capacity of 50 amperes. This arrangement is adapted for one man testing, as it eliminates the necessity of changing the connections or adjustments of the load device for either light or full load readings. The 5 ampere range is provided for testing low capacity watt-hour meters and for light loads on the higher capacity meters. It is also suitable for testing primary watt-hour meters used with current and voltage transformers. In such cases the small wattage consumption permits of connecting the device to a voltage transformer when it would be impracticable to obtain a load for testing in the usual manner.

This load device automatically delivers the proper wattage for light and full loads of all capacity watt-hour meters within its range; that is, when testing watt-hour meters of a given make, the rheostat may be adjusted, with the rotating standard in circuit, to give the desired full load wattage for, say, a 10 ampere watt-hour meter, and, without further change of adjustments, this load device will, when connected to a 50 ampere watt-hour meter, give a full load wattage suitable for a meter of the latter capacity.

A very small rheostat is included within the same case with this device, and is connected in the low-tension circuit. With this rheostat it is possible to gradually vary (not in steps) the wattage from zero up to the full capacity of the box, so that wattage of any desired value between light and full loads may be easily obtained.

The power-factor or phase displacement between the current delivered to the testing circuit and the impressed electromotive force of the line is negligible; the power-factor being practically unity. Even for extreme low loads the power-factor is above 96 per cent.

This box is also supplied with the connections arranged so as to permit of separately controlling light and full loads at the meter. This is accomplished by an arrangement of connections and by employing three, instead of the usual two, current leads. With this equipment no change of connections at the load box, or rotating standard, is required throughout the test, the tester having full con-

trol of the light and full loads separately while at his testing position in front of the meter.

When subjected to conditions met with in watt-hour meter testing, the current is automatically limited to a value which protects the instrument in circuit and the watt-hour meter under test from any damage due to overload. When the low-tension windings are short circuited, the current will not be sufficient to damage the device even if left in circuit continuously. This construction makes the device practically immune to careless handling.

The rated capacity of the Type "H" load box is 50 amperes, which gives an equivalent testing load of 5,500 watts and 11,000 watts at 110 and 220 volts respectively. The device is mounted in a case about 6 inches wide by 7 inches long by 6 inches high, and weighs approximately 8 pounds. Load boxes of 100 and 200 amperes capacity are also manufactured for the various voltages.

Universal Load Boxes, suitable for testing watt-hour meters of any voltage, or ampere, capacity, are manufactured by the Eastern Specialty Company, of Philadelphia, Pa.

Suitable carrying cases for instruments of the rotating standard and indicating wattmeter types are provided by the manufacturers, but for testing requiring the use of two or more instruments, such as a voltmeter, shunt and millivoltmeter, a special instrument box will be found convenient.

A neat and well-appearing box may be made up of oak, well varnished and fitted with brass trimmings. This box may be arranged with three sections, the end ones being for the voltmeter and ammeter or millivoltmeter, and the center one being used as a space for tools, etc. The instruments are placed far enough apart to have practically no magnetic effect on each other and are checked and used in the same relative position. The instrument case may also be made sufficiently large to include the shunt as well as the instruments and tools; but if the capacity of the shunt is very high, the weight will be excessive, so that a separate case for the shunt is desirable. If the shunt and instruments are included in one case, the shunt must be removed when in use, otherwise the heavy currents may cause serious errors in the indications of the instruments (Fig. 332).

When using continuous current millivoltmeters and voltmeters around a switchboard or near conductors carrying heavy currents, they should be placed in suitable **magnetic shield instrument boxes** (Fig. 333) to prevent errors in the indications due to the magnetic effect the heavy currents. A satisfactory shielding effect may be obtained

from a box made of four thicknesses of transformer iron, these being cut in such a way that the four sides may be bent up and fastened by means of brass angle pieces which are riveted to the box. The cover, which is of the same thickness, is fastened by means of four corner screws which pass through it and are driven into lugs which are securely

FIG. 332.—Carrying Case with Instrument Equipment for Watt-hour Meter Testing Edison Electric Illuminating Company of Altoona.

fastened on the inside of the box. Care should be taken to see that all joints are well made and fit closely.

The instrument is placed inside the box and fastened by screws which pass through the bottom and are driven into the wooden base of the instrument. The instrument binding posts are connected to other binding posts which are mounted on the outside of the box

An opening is cut in the cover directly over the reading scale of the instrument. This opening is just the size and shape of the reading scale, so that observations may be easily made. When an instrument is placed in the box, it will cause a change of about 2 per cent in its reading, therefore, it should be carefully checked and corrected, or a calibration curve provided. The outside of the box is neatly trimmed with brass corners and a carrying handle is placed on one end. It is 9¼ inches wide, 8⅝ inches deep and 4 9/16 inches high, and with a Weston portable instrument weighs 15½ pounds.

A hard fiber box similar to a suit case with reinforced corners makes a convenient **tool-carrying case.** This can be arranged with compartments to accommodate a watt-hour meter testing rheostat,

FIG. 333—Magnetic Shield Instrument Box.

tools, slide rules, leads and jumpers without being exceedingly heavy.

A grip, or **tool bag,** should be furnished when there is no other means provided for carrying tools. Extra heavy canvas handbags have been used—also different types of leather handbags and satchels. A very compact tool case has been made of a good grade of heavy black leather with reinforced corners, stiffened at top, bottom and ends, so it will retain its shape. The case is rectangular in shape, being 12 by 6 by 4 inches in size, and contains ample space for the tools required for the testing of all meters, excepting those where special equipment is required. It is furnished with a shoulder strap, which can be shortened, so it can also be carried as a handbag.

In order that the meter tester may perform his work as rapidly as possible, a **slide rule** should be furnished with his equipment.

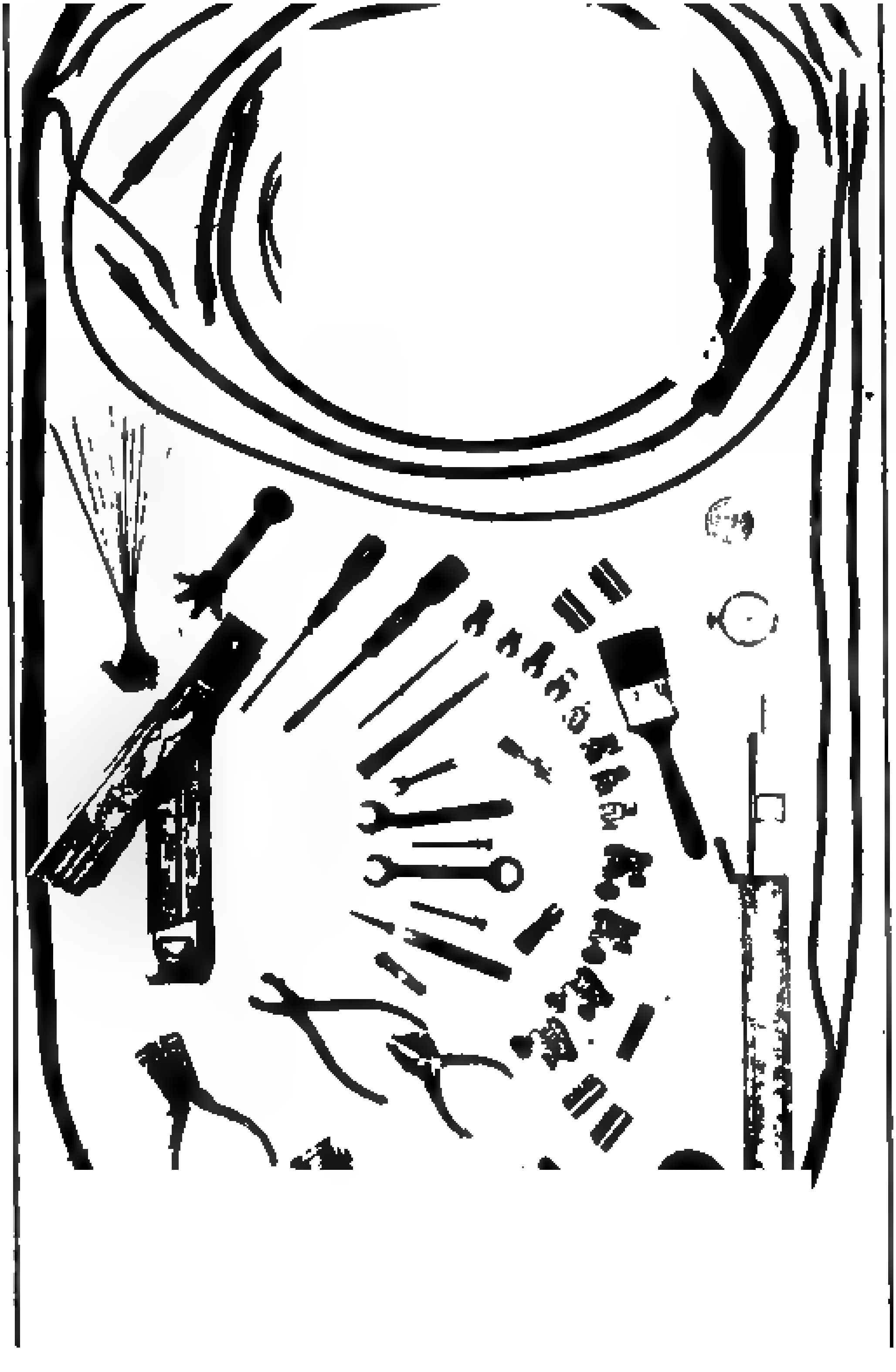


FIG 334 — Watt-hour Meter Tester's Tools and Appliances of the Philadelphia Electric Company.

With this he can calculate his results without having to figure out each step, which is not only more laborious, but is more subject to errors than the slide-rule method. A 10 inch slide-rule should be furnished, and it is preferable that the lower scale be used. A number of good inexpensive rules may be purchased, but care should be used in selecting ones made of well-seasoned wood and constructed in such manner that they are not liable to warp, or expand, under changes of climate or temperature. A rule on which the graduations are engine divided and clearly cut on a background of white celluloid is preferable to one on which the graduations are merely stamped or printed, for in the latter case the reading scale will become worn in time and difficult to read.

In addition to the testing standards, the **meter tester's kit** (Fig. 334) should include connecting leads, a certain number of spare meter parts, seals, adjusting tools, et cetera. The outfit needed differs for different methods of testing, and for different types and capacities of meters. Where the tester has a helper, it is possible to carry a more elaborate outfit than when he works alone. No single standard list will, therefore, suit all conditions. Two lists are given below, the first of which includes things which will be necessary in practically all cases. The second list contains additional supplies, which will be needed in some cases.

MINIMUM EQUIPMENT FOR A WATT-HOUR METER TESTER

Testing standards.
Loading devices.
Badge, or identification card.
Suitable carrying case for tools.
Connectors, leads, etc.
One pair side-cutting pliers.
One six-inch screw driver.
One two-inch cabinet screw driver.
Needles for testing jewels.
One small bottle of best grade jeweler's watch oil.
Supply of jewels and balls or pivots.
Supply of screws, cover nuts, dial hands, etc.
Corn pith for cleaning jewels and pivots.
Assorted fuses.
One air syringe, or camel's hair brush.
Strip of steel for cleaning magnets.

Extension cord and lamps.
Slide rule.
Compound and friction tape.
Cloth, or brush, for cleaning covers, etc.
Supply of seals and sealing tool when necessary.
Special tools, according to make of meter.

ADDITIONAL FOR COMMUTATOR WATT-HOUR METERS

One 4-inch file.
Crocus cloth.
Linen tape.
One commutator pick.
One brush adjuster.

OPTIONAL EQUIPMENT

Level.
Small monkey wrench.
Magnifying glass.
Extra drag magnets.
Extra meter windows.
Brushes for cleaning commutator, worm, etc.
Extra shaft for holding pivots while examining.
One tool for resetting misplaced dial hands.
Pegs of wood for cleaning top bearings, etc.
Magnet wrench.
Flash lamp.
Supply of shafts and top bearings.

A convenient means of carrying and utilizing the tools of a meter tester's kit is illustrated in Fig. 335, which represents a canvas apron with suitable pockets for the reception of the various tools. This apron is worn by the meter tester while in action and permits the convenient use of any required tools. The apron containing the tools may be rolled up and tied, as shown at the right of the figure, during transportation.

Suitable **current leads, pressure leads and jumpers** should be supplied to the tester.

Standard flexible lamp cord may be used for current and pressure leads, but better service will be obtained from high-grade rubber-covered stranded cable.

A single No. 12, B. & S. guage, conductor is suitable for curre

leads used in testing small-capacity meters and two parallel No. 10, B. & S. guage, conductors can be used for current leads up to 100 amperes. Special flexible cable should be used for larger currents. Pressure leads should be made of No. 16, B. & S. guage, flexible conductor.

The use of leads with loose and frayed ends should be avoided, and both current and pressure leads should be equipped with suitable terminals in order to assure perfect contact.

Jumpers should be made of flexible conductor and equipped with

FIG. 335.—Watt-hour Meter Tester's Tools and Appliances in Canvas Apron. United Electric Light and Power Company.

some form of connector or clamp, so they can be readily attached to the line wires, switches or meters.

The jumpers should be of such length that they can be placed far enough from the meter to have no effect on its accuracy.

A regular inspection should be made to see that the leads are kept in first-class condition, and that none of the separate strands of wire are broken. The use of leads with defective insulation should be avoided, as short circuits which may cause injury to the tester or instruments may result from their use. (See Chapter VII.)

CHAPTER X

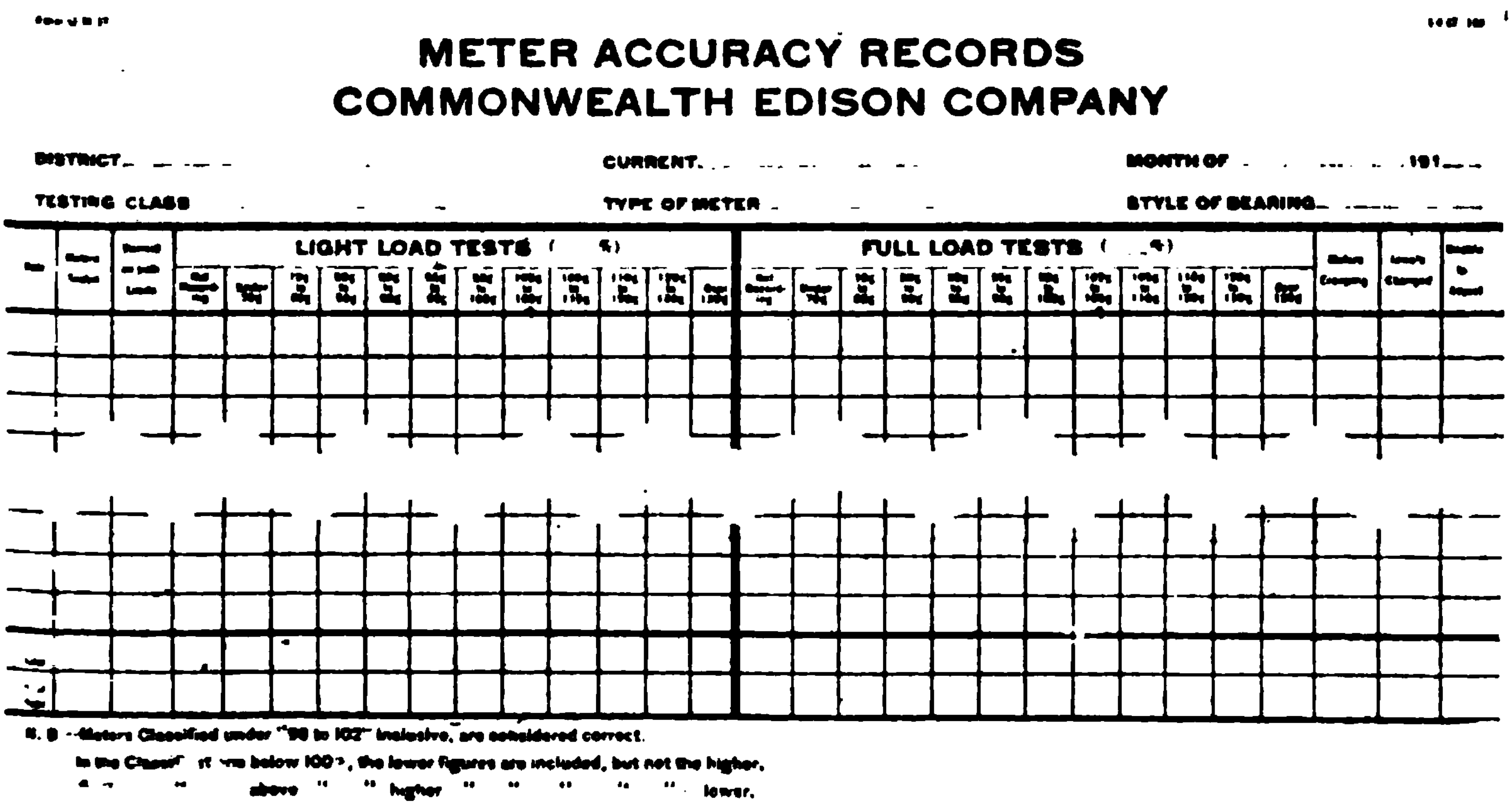
STATISTICS OF WATT-HOUR METER TESTS

CHAPTER X

Statistics of Watt-Hour Meter Tests

A study of the results obtained through systematic methods of watt-hour meter tests can be made of great benefit to the management and to the executives having the responsibility of the accuracy of the metering system, if concise **summaries and statistics,** showing the progress and results of the work, are compiled.

The civic commissions also require certain **statistical forms** to be filed for their information.



METER ACCURACY RECORDS
COMMONWEALTH EDISON COMPANY

DISTRICT
CURRENT
MONTH OF 191
TESTING CLASS
TYPE OF METER
STYLE OF BEARING
LIGHT LOAD TESTS (%)
FULL LOAD TESTS (%)

N. B.—Meters Classified under "98 to 102" inclusive, are considered correct.

Fig. 336.—Form for Daily Tabulation of Watt-hour Meter Accuracy Results.

There are, naturally, very many ways and forms in which these data can be compiled and presented, and each company or individual will undoubtedly exercise considerable latitude in its accumulation and presentation, so as to fit the case in hand. A few suggestions only will, therefore, be given here indicative of the method of tabulating accuracy results, and other statistics from the watt-hour meter test records.

Fig. 336 shows a form on which accuracy results may be entered daily, after the accuracy has been determined and reported on.

The idea is to have a separate sheet for each type of meter. The number of tests that fall within the percentage specified at the head of the vertical columns should be entered in their proper places. For example, if the percentage of accuracy of a meter is

DISTRICT ________________ SIGNED ________________ DATE ________________ 190

LOAD	LIGHT		FULL		LIGHT		FULL		LIGHT		FULL		LIGHT		FULL	
RATIO	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Above 120																
110.1/120																
104 1/110																
102 1/104																
98/102																
96/97.9																
90/95.9																
80/89.9																
Below 80																
Not Running																
TOTAL																

JEWELS REPLACED

No.	TYPE	MILL. OF REV.		
		MAX.	MIN.	AV.

METERS SET	
METERS REMOVED	
METERS REMOVED FOR REPAIRS	
METERS REPAIRED AND TESTED	
METERS TESTED IN ROOM (OLD)	
NEW METERS TESTED	
METERS READ	

FIG. 337.—Form for Monthly Tabulation of Watt-hour Meter Accuracy Results.

found to be 97, it will be entered in the column headed 96 per cent to 97.9 per cent. Heavy load tests should be kept separate and distinct from light load tests. Also where it is practice to test meters on other loads, this third load could have a separate section. In some cases the average percentage of each meter is calculated. This

could also have a separate section. Where there are a very great number of meters tested per day, a suitable filing arrangement, corresponding to the headings of the columns could be arranged and test cards could be first sorted with respect to accuracy at light load, being put into the proper files, and then entered on the statistical form. This could be repeated for heavy load and other loads.

At the end of the month the columns can be totaled, and the per cent of meters tested, that fall within each set of limits, can be determined. For example, if 200 meters were tested and two were found between 96 per cent and 97.9 per cent, the per cent of meters tested that fall within these limits would be one.

At the end of each month the data may be arranged in a condensed tabulated form, which would have the advantage of being more quickly analyzed (Fig. 337).

This idea can, if desired, be carried out to embrace characteristic tests conducted over various periods for specific purposes. This will enable the determination of such questions as the selecting of proper intervals between periodic tests on different types of watt-hour meters, and the superiority of certain types of bearings over others.

Fig. 338 is another form for tabulating accuracy results. Each sheet is assigned a number corresponding to the percentage of accuracy shown by the test, so that each sheet corresponds to a column mentioned above. The serial number of the watt-hour meter tested is recorded in the first vacant space in a column. The numbers 1 to 40 are used for the convenience of totaling the number of tests recorded.

This method provides a ready means of referring to previous meter test cards in case more detailed, or specific information may be desired regarding an individual meter or group.

From these examples, illustrating different degrees of completeness, may be developed any variation of statistical form which may be apropos (Figs. 339, 340 and 341).

Statistics may also be compiled on the meter efficiency, or the cost of testing, repairing or reading watt-hour meters.

These data may be presented also by graphical curves, plotted similarly to Figs. 342, 343 and 344.

Every company, irrespective of its size, should endeavor to keep more or less general **statistical information on watt-hour meters and meter work**; this information will not only be of direct use in the company, but will enable comparison to be made with the results of other companies.

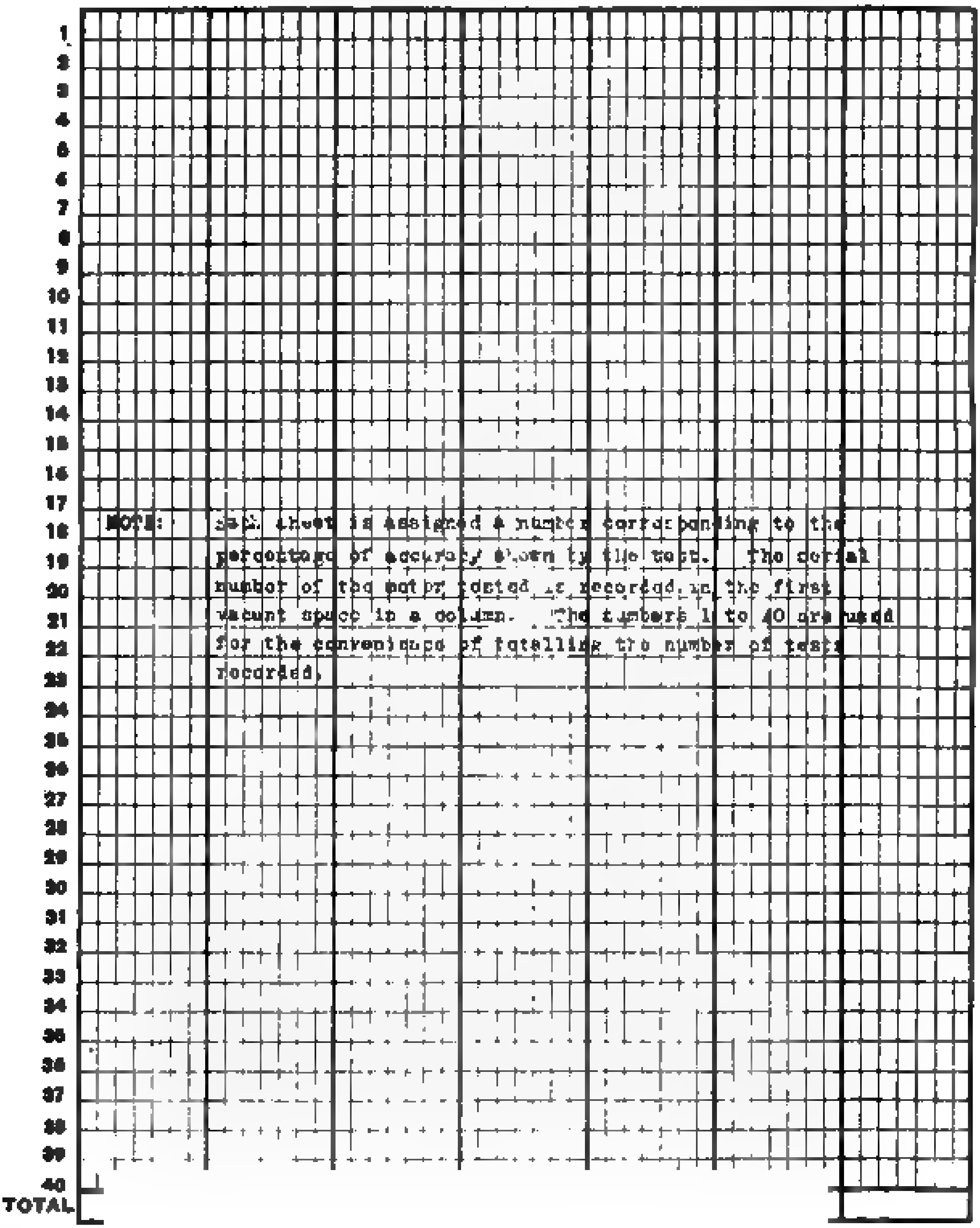


FIG 338

These comparisons often indicate inefficiencies as compared with another, and thus enable a company to improve its methods, where necessary, without expensive experimentation

PERIODIC TESTS OF WATT-HOUR METERS

Final Average Efficiency Per cent	Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.		Total for Year	
	No. of Meters	Per cent	No. of Meters	Per cent	No. of Meters	Per cent	No. of Meters	Per cent	No. of Meters	Per cent	No. of Meters	Per cent	No. of Meters	Per cent	No. of Meters	Per cent	No. of Meters	Per cent	No. of Meters	Per cent	No. of Meters	Per cent	No. of Meters	Per cent	No. of Meters	Per cent
N. R.																										
.001 to 79+																										
80 to 89+																										
90 to 94+																										
95+																										
96+																										
97+																										
98+																										
99+																										
100+																										
101+																										
102+																										
103+																										
104+																										
105 to 109+																										
110 to 119+																										
120 and above																										
Total......																										

FIG. 339.—Form for Yearly Tabulation of Watt-hour Meter Accuracy Results.

In order to assist a company in deciding on the class of statistics it may desire to keep, the following list is presented, which is usually included among the **statistics** kept by the larger companies:

SYSTEM TEST DATA FOR YEAR 1911.

Percent of Correct Registration	Inst. Tests Total–8771		Periodic Tests Total–12901			Complaint Tests Total–514			Office Tests Total–405		
	10% Load	100% Load	10% Load	100% Load	Final Avg. Eff.	10% Load	100% Load	Final Avg. Eff.	10% Load	100% Load	Final Avg. Eff.
Non-recording	0.15	0.10	0.15	0.10	0.10	0.60	0.40	0.40	16.05	13.85	14.10
More than 4% slow	0.55	0.10	2.55	0.25	0.70	3.15	0.80	1.20	21.05	15.85	18.05
96+ to 104	99.25	99.85	96.45	99.20	98.90	95.55	99.30	97.80	78.40	83.80	76.25
98+ to 102	98.55	99.00	81.40	90.95	90.20	81.65	94.80	90.20	65.05	78.85	73.10
More than 4% fast	0.15	...	0.95	0.60	0.45	1.40	...	1.00	1.50	0.25	0.75

Figures show per cent of meters tested falling within given points.

FIG. 340.—Form for Condensed Tabulation of Watt-hour Meter Accuracy Results.

DO NOT WRITE IN THIS SPACE. RESERVE FOR FILING.

To PUBLIC SERVICE COMMISSION FOR THE FIRST DISTRICT, 154 Nassau Street, New York City.

PERIODIC TESTS

Meter tests made during the month of ______________________________, 19____

by the ______________________________ Company.

Manufacturer's name ______________________; Group ________; { A. C. or D. C.

N. B.—A periodic meter test is a test of an electric meter made by an electrical corporation in the regular course of its business upon the premises where the meter is installed, but not at the time of installation, which test is not made as the result of a complaint from the consumer nor by direction of the corporation, of an officer or of an employee that a special test be made.

FINAL AVERAGE EFFICIENCY—PER CENT. (Col. 1)	No. OF METERS (Col. 2)	PERCENTAGE (Col. 3)
0 or Non-Recording		
.0001 to 80		
80 + to 90		
90 + to 95		
95 + to 96		
96 + to 97		
97 + to 98		
98 + to 99		
99 + to 100		
100 + to 101		
101 + to 102		
102 + to 103		
103 + to 104		
104 + to 105		
105 + to 110		
110 + to 120		
120 + and above		
Total		

The plus sign (+) in column 1 is used to indicate any fraction from .0001 up to .9999; thus "90 + to 95" includes every meter found upon final average to register between 90.0001 and 95, both inclusive.

The above report is a correct summary of the tests made by this Company, and all tests were conducted according to the rules of the Public Service Commission, as prescribed in Final Order adopted October 26, 1909, in Case No. 1154.

____

Form G [illegible]

FIG. 341.—Form for Submission of Tabulation of Watt-hour Meter Accuracy Results to Civic Commission.

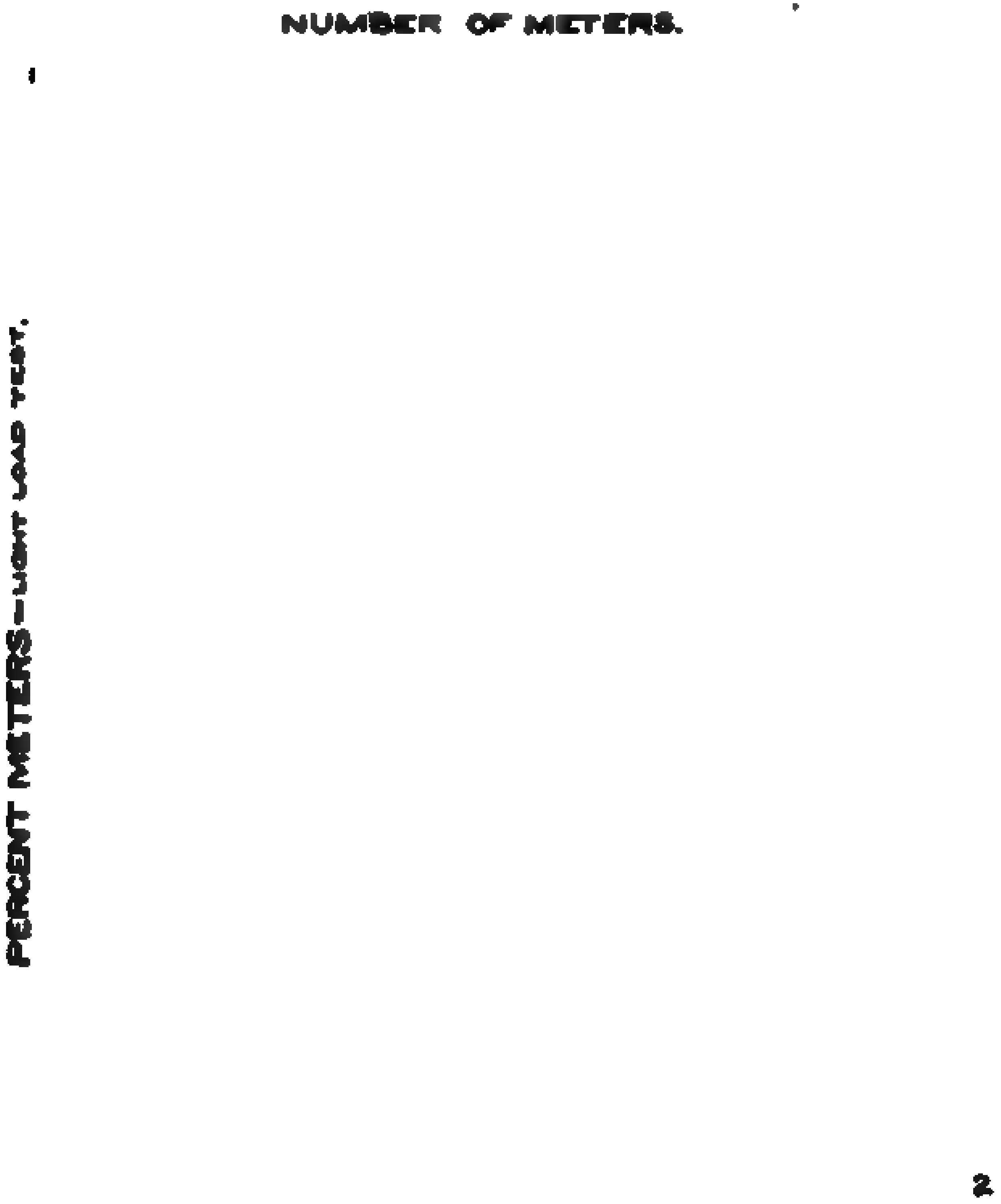


Fig. 342.

Watt-hour Meters—

Accuracy as explained above and in Chapter XI.

Number in service on the first of each month, subdivided according to make, type, capacity in amperes, volts and wire, et cetera, and also divided under light and power.

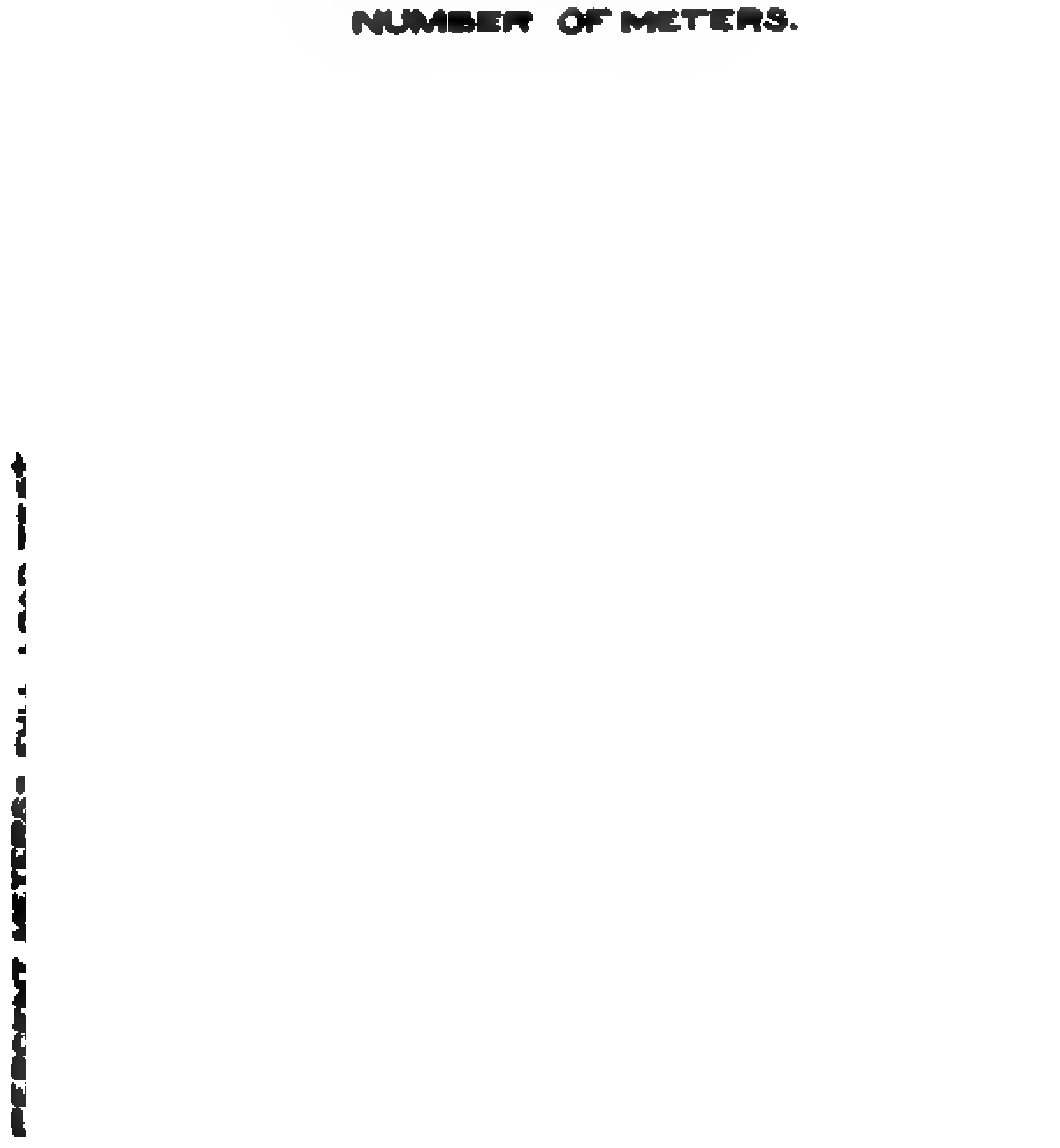


Fig. 343.

Number in stock on the first of each month, number purchased and number destroyed, or scrapped, during the month, and so on.

Number of meters found defective in service each month, subdivided under causes and make, et cetera (Fig. 345).

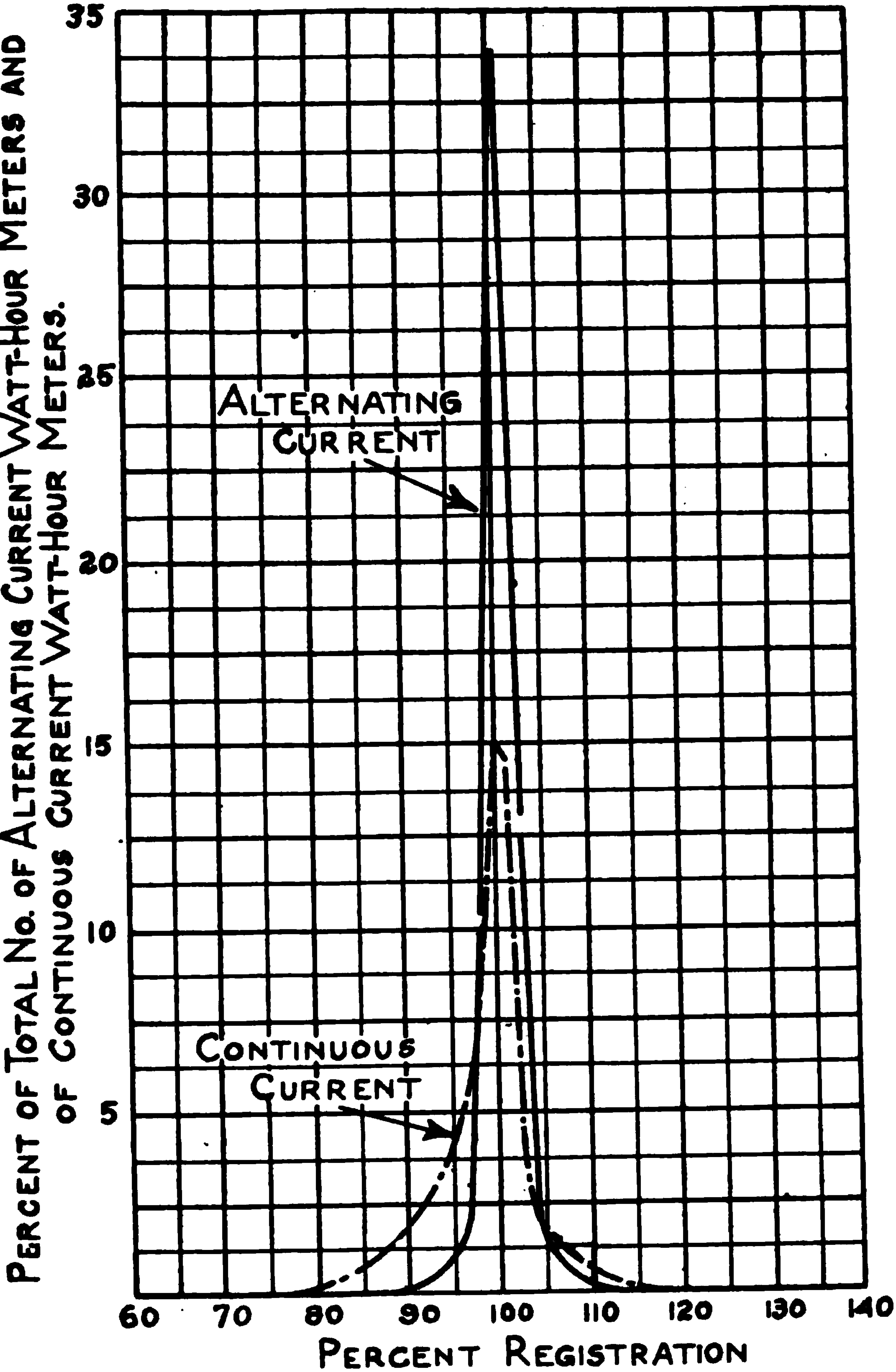

35
30
25
20
15
10
5
60
70
80
90
100
110
120
130
140
ALTERNATING CURRENT
CONTINUOUS CURRENT
PERCENT OF TOTAL NO. OF ALTERNATING CURRENT WATT-HOUR METERS AND OF CONTINUOUS CURRENT WATT-HOUR METERS.
PERCENT REGISTRATION

FIG. 344.

DAILY METER STATUS

SECTIONS DECREASED BY DAILY OPERATIONS	SECTIONS INCREASED BY DAILY OPERATIONS				TOTAL DEDUCTION	REMARKS
	IN STOCK	INSTALLED	IN SERVICE	CUT OUT		
IN STOCK						
INSTALLED						
IN SERVICE						
CUT OUT						
TOTAL INCREASE						
TOTAL DECREASE					TOTALS	
GAIN AND LOSS						
NUMBER PURCHASED						
LOST OR CONDEMNED						
PREVIOUS STATUS						DATE
PRESENT STATUS NUMBER OF METERS	IN STOCK	INSTALLED	IN SERVICE	CUT OUT	OWNED	BY

(Obverse Side.)

RECORD OF TRANSACTIONS

METER OPERATIONS	THIS DAY	THIS MONTH	THIS YEAR	REMARKS
REMOVED				
INSTALLED				
CUT IN				
CUT OUT				
PURCHASED				
CONDEMNED				
LOST				

(Reverse Side.)

FIG. 345.—Form for Tabulating Status of Watt-hour Meter Stock.

Installation—

Total number of meters installed Total number of meters removed Number of meters changed.....	The subtraction of the latter from each of the other two gives the new installations and final removals.
Average cost of installing meters Average cost of removing meters Average cost of changing meters	Each subdivided under Labor, Material and Miscellaneous.

Tests—

Number of meters tested, subdivided under the various classes of tests previously mentioned; as installation tests, periodic tests, and so on.

Number of meters tested per day per tester, and per team separately.

Average cost of service test............ Labor.
Material.
Miscellaneous.

Average cost of shop test.............. Labor.
Material.
Miscellaneous.

Repairs—

Number of meters repaired, subdivided according to make, and so on.

Average cost of repairs per meter...... Labor.
Material.

Maintenance—

Cost per test for repairs of testers' tools and appliances.

Cost per test of checking and repairing testing instruments.

Total cost per meter per year for repairs and testing.

Reading—

Number of meters read and percentage of errors.

Number of meters read per man.

Average time per reading on each route.

Average cost per reading.............. Labor.
Miscellaneous.

Complaints—

Number of complaints per month and percentage of justifiable complaints.

Percentage of complaints received to bills rendered.

The above general headings can be subdivided to as great a degree of detail as may be found desirable.

While the different methods of accomplishing the meter work in detail may necessarily vary widely with the different organizations, it is still possible to so **classify the expense** under divisions and subdivisions as to accomplish reasonable uniformity. Some companies may desire to carry this subdivision into much greater detail than others

There is great need of being able to compare notes more fully on such points as "Cost per meter of system tests" and "Costs per year per meter maintained," with the knowledge that the costs are figured on the same basis.

A suggested method of accomplishing the calculation of these items is given below as a guide for **uniform accounting** in connection therewith.

METER DEPARTMENT EXPENSE

	Numbers	Proportion of Expense Allotted to Service	[illegible]	Station Meters and Instruments	Laboratory Instruments	Sub-totals	Totals
I. OFFICE.							
(A) Commercial Expense.							
(1) Reading and Records.							
(*a*) Supervision and Clerical Payroll							
(*b*) Stationery and Postage.							
(*c*) Miscellaneous Expense.							
(*d*) Total Expense.							
(B) Distribution Expense							
(1) Testing and Repairing.							
(*a*) Supervision and Clerical Payroll							
(*b*) Stationery and Postage.							
(*c*) Miscellaneous Expense.							
(*d*) Total Expense.							
Number of Men.							
Average Expense per Meter on System							
II METER SHOP.							
(A) Distribution Expense.							
(1) Testing							
(*a*) Payroll.							
(*b*) Material.							
(*c*) Supplies and Expenses.							
(*d*) Instruments and Apparatus.							
(*e*) Total Expense.							
Number of Testers.							
Number of Helpers.							
Number of Meters Tested.							
Average Expense per Meter Tested							
Average Expense per Meter on System.							
(2) Repairing.							
(*a*) Payroll.							
(*b*) Material.							
(*c*) Supplies and Expenses.							
(*d*) Instruments and Apparatus.							
(*e*) Total Expense.							
Number of Repairmen.							
Number of Meters Repaired.							
Average Expense per Meter Repaired							

METER DEPARTMENT EXPENSE—*Continued.*

	Numbers	Proportion of Exper		
		Service Watt-hour Meters	Maximum Load Indicators	Station Meters and Instruments
III. System.				
(A) Commercial Expense.				
(1) Reading.				
(*a*) Payroll.				
(*b*) Material and Supplies.				
(*c*) Incidental Expenses.				
(*e*) Total Expense.				
Number of Meter Readers.				
Number of Meters Read.				
Number of Meters Read per Man.				
Total Errors in Reading.				
Per cent of Incorrect Readings.				
Average Expense per Meter Read.				
Average Expense per Meter on System.				
(B) Distribution Expense.				
(1) Testing.				
(*a*) Payroll.				
(*b*) Material.				
(*c*) Supplies and Expenses.				
(*d*) Instruments and Apparatus.				
(*e*) Total Expense.				
Number of Testers.				
Number of Helpers.				
Number of Meters Tested.				
Average Expense per Meter Tested.				
Average Expense per Meter on System.				
(2) Repairing.				
(*a*) Payroll.				
(*b*) Material.				
(*c*) Supplies and Expenses.				
(*d*) Instruments and Apparatus.				
(*e*) Total Expense.				
Number of Repairmen.				
Number of Meters Repaired.				
Average Expense per Meter Repaired.				
Average Expense per Meter on System.				
IV. Summary and Statistics.				
(*a*) Average Number of Watt-hour Meters on System.				
(*b*) Total Expense for Meters.				
(*c*) Office Expense per Meter on System.				
(*d*) Meter Shop Expense per Meter on System.				
(*e*) System Expense per Meter on System.				
(*f*) Total Expense per Meter on System.				
(*g*) Average Number of Maximum Load indicators on System.				
(*h*) Total Expense for Maximum Load Indicators.				
(*i*) Total Expense per Maximum Load Indicator on System.				

CHAPTER XI

WATT-HOUR METER RECORDS

CHAPTER XI

Watt-hour Meter Records

No matter how few meters a company may have, it will be found advisable to **keep proper records of the meters and meter work.**

In the whole routine of a central station company, no matter is of more importance than the proper care and handling of meters and meter records.

It is just as important to throw safe-guards around the company's meters and meter records as it is to protect the cash receipts and expenditures, for the reason that the revenues of the company are absolutely and directly dependent upon the meters and their readings.

A meter immediately upon being purchased should be tagged as the property of the company, badged with a serial number and taken into a monthly balance. It should be accounted for during its entire life history with the company, so that its location and its performance can at all times be readily known and checked, even after it has been condemned and disposed of as scrap.

Like the employees, the meter should pass inspection and examination upon entering the service of the company, should be selected for the work that it is to do, should be definitely assigned to such work, its performance should be inquired into from time to time in order that it may do its work efficiently and well, it should receive all the attention necessary to maintain it in good operating condition, and should finally be dismissed with honor and its work regarded with respect.

It will be found advantageous to **outline a sufficiently comprehensive system** to take care of the natural increase in the number of meters and corresponding increase in meter work. To outline a thoroughly comprehensive system of meter records is difficult, as local conditions largely govern the system to be adopted.

Some companies provide a suitable **meter test record card** for each meter, upon which all information, such as date of purchase, manufacturer's and company's serial numbers, capacity in amperes, volts and type, constants, and any other descriptive information is entered. The card also contains spaces for the name and address of each consumer in whose premises the meter has been installed, the date of installation and

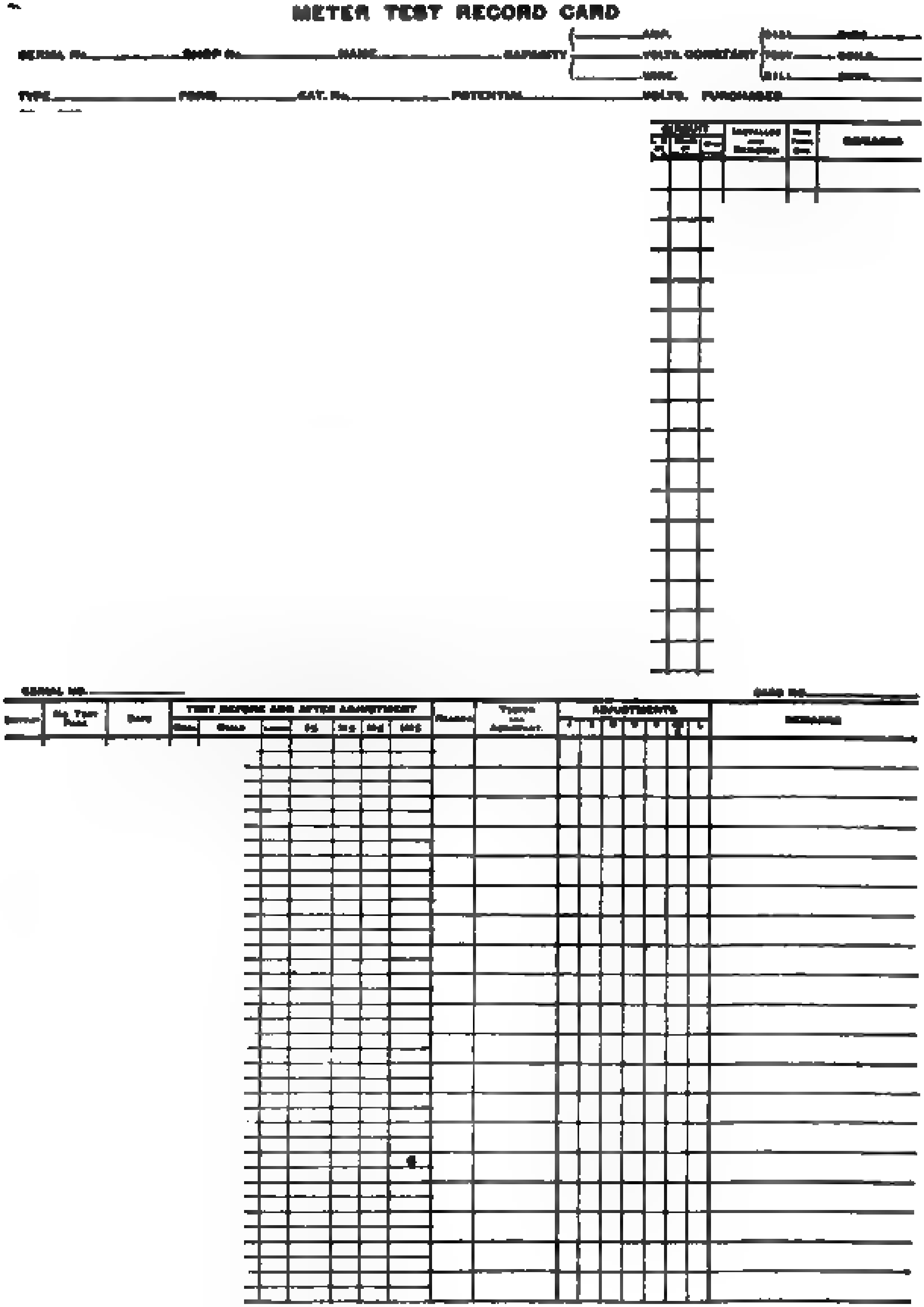
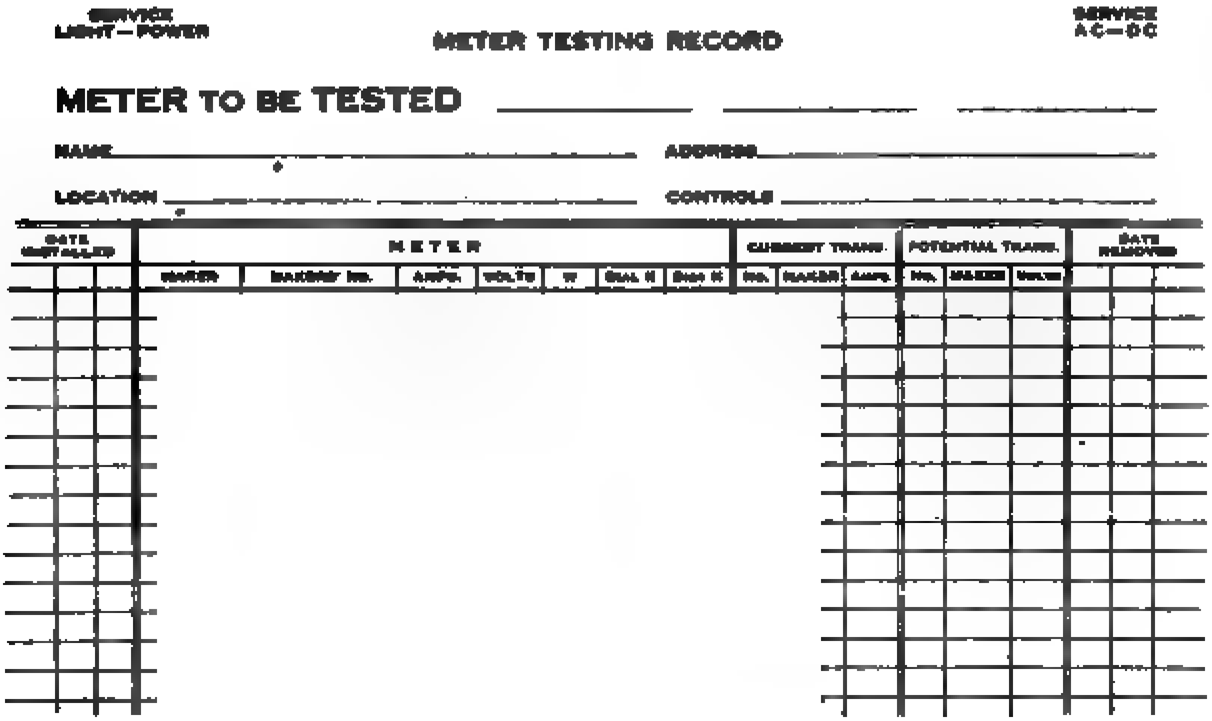


FIG. 346.—Watt-hour Meter Test Record Card. Obverse and Reverse Sides.

removal, and a copy of all tests. This card, therefore, serves as a record of the meter from the date of its receipt until it is finally discarded (Figs. 346 and 347).

Some companies have a meter record envelope, filed numerically according to the number of the meter, which is stamped on the outside. In this envelope are filed all watt-hour meter test forms and records of installation and removal pertaining to that meter. The date of purchase of the watt-hour meter and the dates when tests were ordered and performed are stamped on the outside.

Some companies keep a record of their meters and of their con-



SERVICE LIGHT—POWER — METER TESTING RECORD — SERVICE AC—DC

METER TO BE TESTED

NAME — ADDRESS

LOCATION — CONTROLS

DATE INSTALLED | METER (MAKER, MAKER'S No., AMPS., VOLTS, W) | CURRENT TRANS. (No., MAKER, AMPS.) | POTENTIAL TRANS. (No., MAKER, VOLTS) | DATE REMOVED

Fig. 347.—Watt-hour Meter Test Record Card.

sumers on **numerical and alphabetical index cards**, usually designated as the numerical and alphabetical indices. The numerical index contains a card for each separate watt-hour meter, and the cards are filed numerically, according to the company's serial numbers. The card gives the capacity of the meter, and similar data, also the name and address of the consumer in whose premises it is installed (Fig. 348).

The alphabetical card includes the name and address of the consumer and is filed alphabetically or geographically. Upon this card are entered the numbers and other data of all the watt-hour meters installed the consumer's premises (Fig. 349).

Given the company's serial number of the meter, it is possible by these

[illegible]

NUMERICAL METER RECORD

SERIAL NO. ______ SHOP NO. ______ DIAL CONST. ______

NAME ______ AMPS. ______ VOLTS ______ WIRE ______

FORM ______ CAT. NO. ______ TYPE ______ CONNECTIONS ______

DISTRICT AND ROUTE	NAME	ADDRESS	
			1
			2
			3
			4
			5
			6
			7
			8
			9
			10

[illegible]

indices to locate the premises in which the meter is installed, and vice versa.

All companies should enter the results of their watt-hour meter

Address ....

Name ....

....

Occupied as ....

Meter No. ....

Size .... *Make* ....

Location ....

Remarks ....

Installed ....*191*............*Route No*......

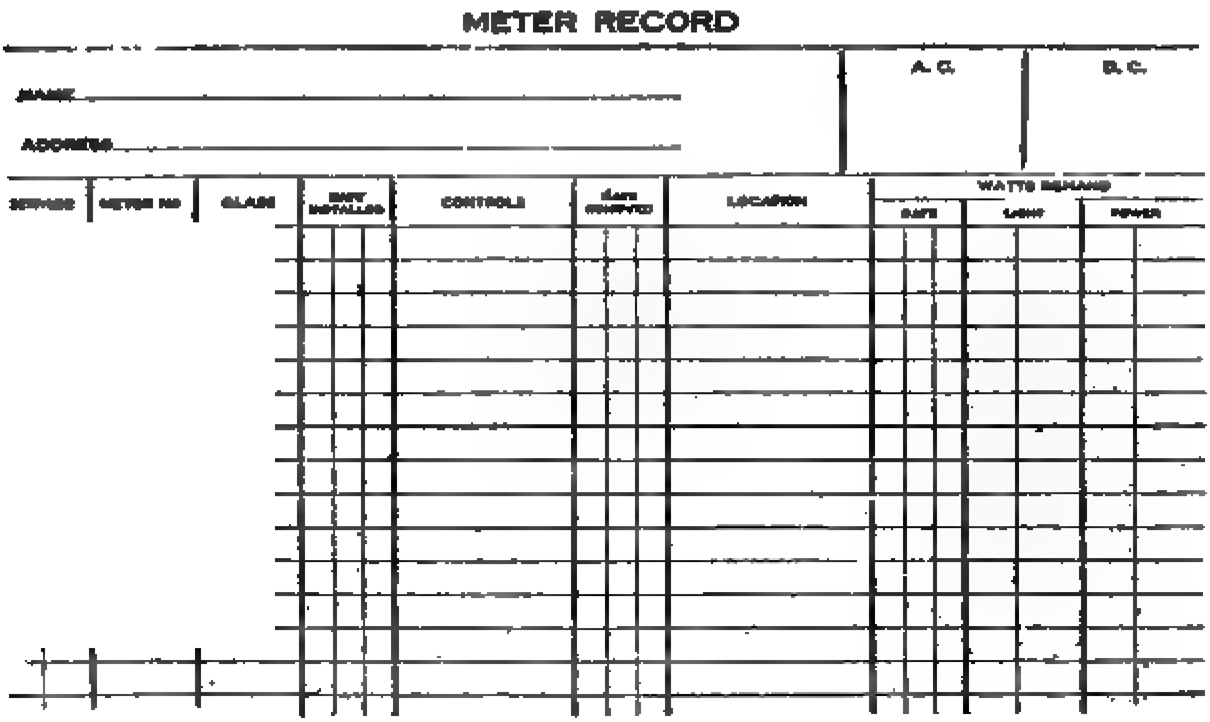


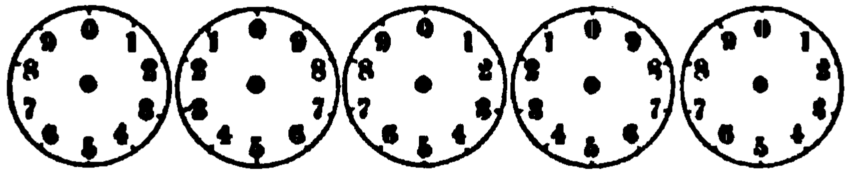
FIG. 349.—Geographical and Alphabetical Indices for Watt-hour Meter Record.

tests on suitably prepared **system test forms** (Fig. 350), which should b carefully filed for future reference. Some companies use a separate shee

DATE ______________ 190_

Consumer ______________________________

Address ______________________________



Reading { At Start ____________ " Finish ____________ Constant { Dial ____________ Testing ____________

Serial No. __________ Factory No. __________ Style ____________

Amp. ____________ Volts ____________ 2 or 3 Wire.

Location { Erected on ______________________ In ______________________ Occupied as ______________________

Circuit __________ Wire __________ Volts at Meter { Pos. Neg. _____ Side __________

LOAD { Lamps _______ 8 C. P. _______ 16 C. P. _______ 32 C. P. _______ Base Motors ____________ Fans ____________ Arcs ____________ Miscellaneous ______________________

Wattmeter No. __________ Voltmeter No. __________ Ammeter No. __________

Milli-Voltmeter No. __________ S. B. No. ________ Stop-Watch No. ____ Seal ________

Time Enter TEST BEFORE ADJUSTMENT

%		Volts	Amperes	Rev's	Seconds	Standard Watts	Meter Watts	%
5								
33								
100								

CREEPING, CONTINUOUS, OCCASIONAL Due to ______________

Time Leave TEST AFTER ADJUSTMENT

5								
33								
100								

CREEPING, CONTINUOUS, OCCASIONAL Due to ______________

Lamps Required to Start, Before Adj. ______________ After Adj. ______________

Reason for Test __________ New __________ Exchange __________ Meter __________

ADJ.	A	B	C	CC	D	E	F	G	J	L	M	P	R	S	T	U	V

REMARKS: ______________________________

____

____

____

TESTED BY ______________________ ASST. ______________

Last Test: By ____________ Date ____________ Seal Left ______ Seal Found ______

FIG. 350.—Form for System Watt-hour Meter Tests.

card (Fig. 351). Some companies enter in detail a record of all adjustments, sometimes employing a code to abridge the work, while others enter only the bare results of the test, omitting any details of adjustment, or other data (Fig. 352).

It is probably more desirable to err on the side of too much information than too little, and the suggestion is made that not only should the results of the tests be entered, but also sufficient information to explain the cause of any inaccuracy in the meter and the adjustment necessary

Periodical ( ) Complaint ( ) Incoming ( )
Light ( ) Power ( ) Business
Installed **Location**
Meter **Type**
Date Tested **Time**

	AS FOUND			AS LEFT		
Load	Stand.	Meter	Per Cent.	Stand.	Meter	Per Cent.
5%						
10%						
25%						
75%						

Reading **Dial K** **Disc K**

Adj. Shunt	Armature
Adj. Magnets	Resistance
Brushes	Dial
Commutator	Disc
Jewel	Creeping
Pivot	Leveled
Shaft	Inspector

Periodical ( ) Complaint ( ) Incoming)
Light ( ) Power ( ) Business
Installed **Location**
Meter **Type**
Date Tested **Time**

	AS FOUND			AS LEFT		
Load	Stand.	Meter	Per Cent.	Stand.	Meter	Per Ct.
5%						
10%						
25%						
75%						

Reading **Dial K** **Disc K**

Adj. Shunt	Armature
Adj. Magnets	Resistance
Brushes	Dial
Commutator	Disc
Jewel	Creeping
Pivot	Leveled
Shaft	Inspector

FORM NO. [illegible]

FIG. 351.—Form for Four System Watt-hour Meter Tests. Similar on Both Sides.

to recalibrate it. A record of the meter stock may be kept on a form similar to Fig. 353.

The warrantable expense and trouble in which each company can involve itself must be left to individual judgment, and no recommendation accompanies the suggestive exhibition of forms given here, the idea being to cover the range from the simple to the elaborate, allowing the company's policy to dictate the detail to be included in each case.

Uniformity in size and form of all records should receive far more study and consideration than it usually does, from the standpoint of the printing, the paper waste and general convenience and economy. It is therefore suggested that a basis be established, consisting say of the com

THE UNITED ELECTRIC LIGHT AND POWER COMPANY
1170 BROADWAY

METER No. ______ Date ______

Customer ______

Address ______

Meter Cut In ______ Installation ______ Customer's Normal Load ______ K.W.

Location of Meter ______ Part Supplied ______

Reason for Test ______ LABORATORY. INSTALLATION. PERIODICAL. OFFICE. COMPLAINT.

Remarks ______

Date of Last Test ______ Final Average as Found ______ As Left ______

CORRECTED AVERAGE PER CENT. EFFICIENCY OF CUSTOMER'S METER

As Found on 10% Load ______ Normal Load ______ 100% Load ______ Final Average ______

As Left on 10% Load ______ Normal Load ______ 100% Load ______ Final Average ______

Date Tested ______ By ______ Time ______ A.M. P.M.

	AS FOUND			AS LEFT		
LOAD	CUSTOMER'S METER	STANDARD	AVERAGE PER CENT. EFFICIENCY	CUSTOMER'S METER	STANDARD	AVERAGE PER CENT. EFFICIENCY
10%...						
NORMAL						
100%...						

Reading of Customer's Meter ______ K.W. Hours   Reading of Customer's Meter ______ K.W. Hours

One Division of First Dial ______ K.W. H'rs   Shunt as Found ______

No. of Standard Used ______ Voltage Coil Used ______

Correction Factor for 10% Load ______ Normal Load ______ 100% Load ______

(SEE REVERSE SIDE FOR REPAIRS AND REMARKS)

FIG. 352.—Obverse. System Watt-hour Meter Test Form.

pany's letter head, which is 8 inches by 10½ inches, and that all records be made of such sizes as to be fractional or multiple parts of this sheet. A more convenient size of letter head has recently come into use, namely 7¼ inches by 10½ inches, which folds with two horizontal folds and fits

TIME TEST OF METER

	READING AT START	READING AT FINISH	EFFICIENCY
STANDARD NO.	....	....	....
METER NO. ________	________	________	________

METER ________ ON 150% VOLTAGE

NO ACCESS				PROBABLY ACCESSIBLE	

REPAIRS AND ADJUSTMENTS

MATERIAL USED		PART REPAIRED	OPERATION	REMARKS
NEW SHAFT JEWEL		REGISTERING TRAIN	CLEANED OILED	
NEW LOWER JEWEL		MAGNETS	ADJUSTED	
NEW TOP BEARING		LIGHT LOAD	ADJUSTED	
NEW BALL		FIELDS	BALANCED	
NEW SHAFT		BEARINGS	CLEANED OILED	
NEW COVER				
PUNCHED DISK				
BEARING PLATE				
METER CONNECTION BLOCK				

FIG. 352.—Reverse. Watt-hour Meter System Test Form.

snugly into an envelope 7½ inches by 4 inches. This size multiplies, or divides, conveniently into thirds, or other fractional, or multiple sizes, which have a desirable relation to the company's letter heads.

A very common oversight which, to use a "bromidic" expression

shows the tendency of some to view a broad subject "through a small bunghole," or else an inclination toward egotism, is the omission on the records of any reference to the company's name, or location. In view of the cooperative attitude assumed by companies in the distribution of information and interchange of ideas, and of the desirability of completeness, this matter should not be overlooked.

In the present **exhibit of forms,** the desirable features just discussed could not be exemplified, as the records were collected from various companies, some of whom have requested the elimination of their name, and as the necessary reduction to proper printing size precludes any relation of sizes in the figures, if it had existed in the originals.

COMMONWEALTH EDISON COMPANY.
METER STOCK RECORD

MAKE........TYPE........AMPERES........VOLTS........WIRE........PHASE........

DATE	CHARGES						CREDITS						BALANCE METERS IN STOCK
	METERS BOUGHT	METERS CUT OFF					METERS SOLD	METERS INSTALLED					
		DIST.	DIST. C	DIST. D	DIST. E	TOTAL		DIST. A	DIST. C	DIST. D	DIST. E	TOTAL	

FIG. 353.—Form for Watt-hour Meter Stock Record.

The following is a **list of the several entries,** one or more of **which have been used,** on the forms of meter test record cards, by **different** companies, but it omits such items as are obviously of local interest only: and from this list any company can prepare its own meter test record card to fit its local conditions.

Local Data

Name of Company; Date....................19..........; Test Card No. or Slip No.......................; District...................; Station............; Route...............; Order No..................; Trip No..........; Ledger..............; Page......................; Folio No..........; Bookkeeper.......................................; Cost of Repairs..

Consumer

Name ....; Address ....;
Occupied as....................; Character of Place................
Business.......................; Time entered premises............
.... a. m. / p. m. Time left premises........................ a. m. / p. m.

Service and Load

Alternating Current or Continuous Current....................;
Volts, pos. side...........; neg. side...........; outside............;
Service Wiring .... two-wire .... / three-wire........;
House Wiring .... two-wire .... / three-wire........;
Kind of Load or Installation......................................;
Connected Load..............; Lamps............; 8 c.-p..............;
16 c.-p.......................; 32 c.-p............watts............
Motors...................; Arc Lamps..............................;
Fans......................; Heating Device.........................;
Miscellaneous or Special...; Normal Load........; kw................;
Estimated Average Load in Amperes..................................;
State What Current is Necessary to Carry Full Load.................;
Motor Current ....; Inrush..............; Power-Factor....;
Ground on House Wire..; Tested Clear; Ground
Short Circuits...

Meters

Serial or Company's No....................; Shop or Manufacturer's No.............; Catalog No.............; Style No..........;
Name of Meter or Maker........................; Type.............;
Form ....; Wire..................; Phase.............;
Capacity—Amperes.....; Volts.................; Location of.......;
Meter: Erected on.....; In....................; Occupied as.......;
Good ....; Bad ..; Damp..................; Dusty.............;
Accessible ....; Inaccessible ....;
Used for Lighting....; Power.......................................;
One Division of First Dial Equals..................................;

Constant and Ratios

Test Constant (K_t)..........; Watt-hour Constant (K_h)...........;
Watt-Second Constant (K_s)...; Register Constant (K_r)................;
Register Ratio (R_r)..........; Gear Ratio (R_g)...................;
Current Transformer Ratio...; Voltage Transformer Ratio...........

Meter Test

Meter as Found................; Meter as Left................;
As Found............; As Left............; Found............;
Left..................; or Test Before Adjustment.................;
Test After Adjustment....................................

Per Cent Load...........................	Indicating Instruments
Standard Volts	
Standard Amperes	
Standard Watts	
Meter Watts	
Revolutions	
Seconds	
Error or Difference in Watts................	
Error in Per Cent { Fast / Slow	
Percentage of Accuracy......................	
Average Error in Per Cent...................	

Revolution of Rotating Standard................	Rotating Standards
Revolution of Meter (Correct Number)..........	
Revolution of Meter (Actual)..................	
Percentage of Accuracy........................	
Observed Revolutions— { Standard (a) / Meter (b)	
True Ratio Revolutions— { Standard (a) / Meter (b)	
Percentage of Accuracy equals (b) divided by (a).	
Standard Revolutions times Test Constant (Equals Standard Watts).................	
Meter Revolutions times Test Constant (equals Meter Watts)	
Percentage of Accuracy........................	

Test Data

Reason for Test...;
Date of Previous Test...19...;
Class of Test: Periodic, Initial—Retest,
Special—Complaint, Inquiry; Time of Test, from
.... a.m./p.m.; to............................ a.m./p.m.
Tested with Lamp Bank; Storage Battery; Water Rheostat; Standard Lamps No..........................Transformer, etc.;
Date Calibrated.......................; Consumer's Load............;
Kilowatt-hours Used in Test...;
Method of Test.......................; Formula of Meter...........;
Tester ....; Assistant ....;
Checked by..........................

Instruments

Ammeter No.................; Voltmeter No.................;
Millivoltmeter......................; Wattmeter No................;
Stop Watch.........................; Rotating Standard No..........

Conditions

As Found—

Register Reading...............; Meter Sealed...............;
Seal......... { Terminal / Cover ; Starting Current............;
Creeping, occasional, continuous, back, forward.........................;
Creep Due to..........................; Rate of Creep...............;
Rev..........Min..........Sec.......... Hours per Day..............;
Watt-hours per Day ....; Errors on Starting..........;
Load..........Per Cent..............; Leveled.......................;
Shunt Wire Soldered; Tested Field in Shunt Coil..........................;
Condition of jewel, pivot, top bearing, gear, worm gear, field coil, shunt coil, resistance, armature, commutator, brushes dial hands disk, in general.

As Left—

All items under "As Found," and also the following:
Brush tension—light, medium, heavy, right and left; Adjusted—shunt

bearing, brushes; Changed—jewel, shaft, pivot, disk; Cleaned—commutator, brushes, magnets, gears; Jewel—cup diamond, sapphire, ball bearing; Increase of Volts Above Normal to
Cause Creep.....................; Meter Left.....................;
Service Left.....................

Space for remarks on the sheet or card should always be supplied; and in some cases where only one side of the sheet, or card, is used, remarks may be put on the back.

In order to lessen the work of recording the adjustments, et cetera, various codes have been adopted, one of which is as follows:

CODE

A.	Armature.	M.	Magnets.
B.	Brushes.	N.	Wing Nut.
C.	Commutator.	O.	Cover (The "Outside.")
C.C.	Compensating Coil.	P.	Phasing Coil or Coils.
D.	Disk.	Q.	Shunt Circuit, Secondary.
E.	Shaft End.	R.	Resistance.
F.	Field Coils, Main Coils.	S.	Shaft.
G.	Gearing in Register.	T.	Top Bearing.
H.	Dial Hands.	U.	Wiring (Conditions, Size, Etc.)
I.	Impedance Coil.	V.	Vibration.
J.	Jewel.	W.	Worm.
K.	Compensator.	W.W.	Worm wheel.
L.	Level, Leveled.		

The terms generally used on the meter test cards have also been abbreviated, such as "Adj." Adjusted; "Br." Bridged, et cetera.

It is very desirable to tabulate **the meter accuracy tests** for the purpose of determining the number that are within certain limits of accuracy: also the number fast and slow on both full and light loads. This can be tabulated separately for each type and make of meter. By this means, companies are enabled to keep accurate records not only of the meters, but of the efficiency of the meter department. See Chapter X.

CHAPTER XII

READING OF SERVICE WATT-HOUR METERS

CHAPTER XII

Reading of Service Watt-hour Meters

The reading of service watt-hour meters, or recording of the consumption of electrical energy used by the consumers, as shown by the registration of the watt-hour meter, is accomplished by different methods in different companies. Most of the small companies read all of their watt-hour meters during the last few days of the month, and the bills are presented about the first of the following month. Larger companies divide their territory into districts, reading one or more districts each day, and the bills for the month's consumption are presented as soon as possible after the meters are read. It is desirable that certain watt-hour meters, such as meters in theaters, be read weekly, and some special meters are read only on the last day of the month for the convenience of consumers who desire to keep their accounts by the calendar month.

Whether bills are all made out at the end of the month, or are distributed over the entire period, the invoice covers a period, usually approximately one month, previous to the date of reading and the consumer is allowed a certain time, usually ten days, in which to discount his bill for prompt payment.

When a company's growth would so indicate it may be policy to change from the system of reading all meters at the end of the month to that of reading a certain number each day. Some companies adopt an intermediate stage, and divide their territory into four districts, reading one district during part of each week and billing during the remainder of the week, effort being made to always read each meter on corresponding days of each month. When changing to the daily system of reading, it is advisable to divide the city into not more than twenty-four parts. The month generally contains twenty-six working days, and the last two days are then available for special readings, delayed readings and other incidental matters.

Two methods are used for the recording of the readings by the meter readers—recording the readings directly in figures, or marking the positions of the dial hands on a printed facsimile of the dial
f... The advantages claimed for the first method are that th

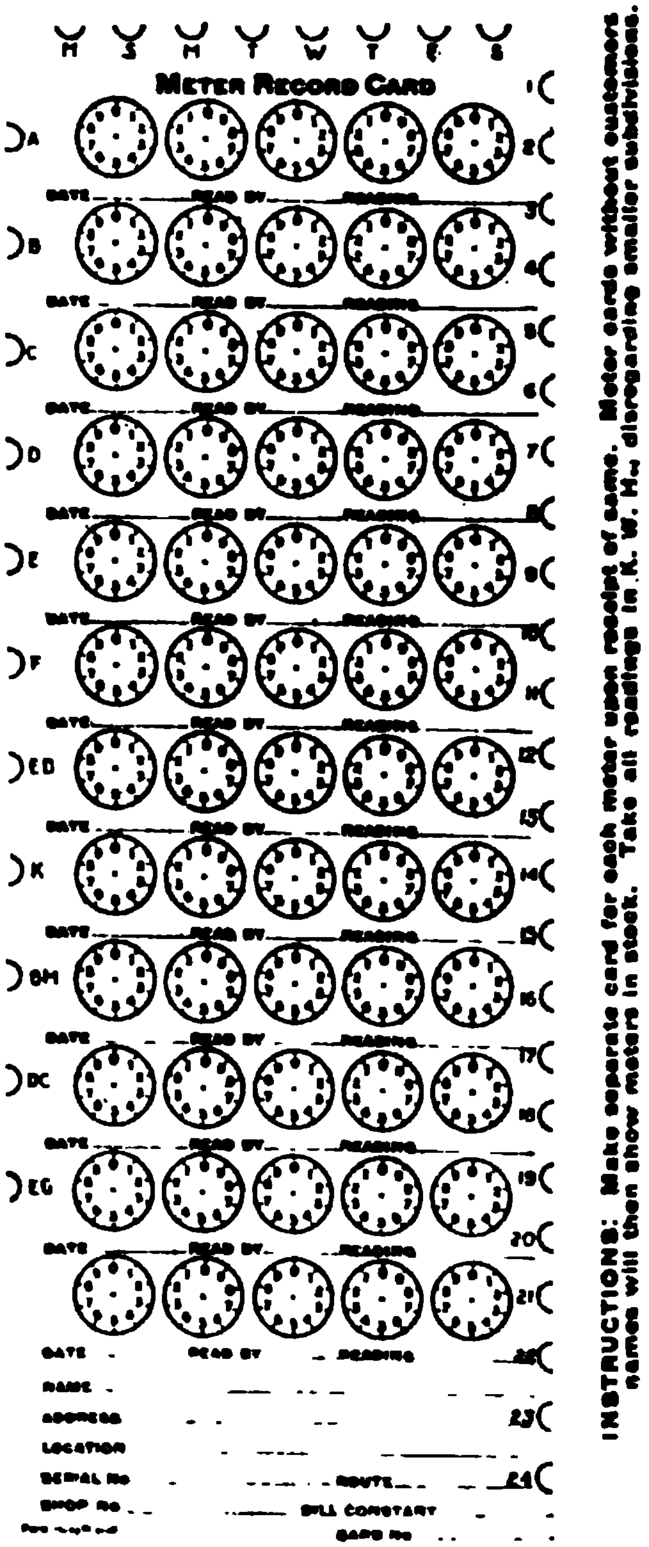
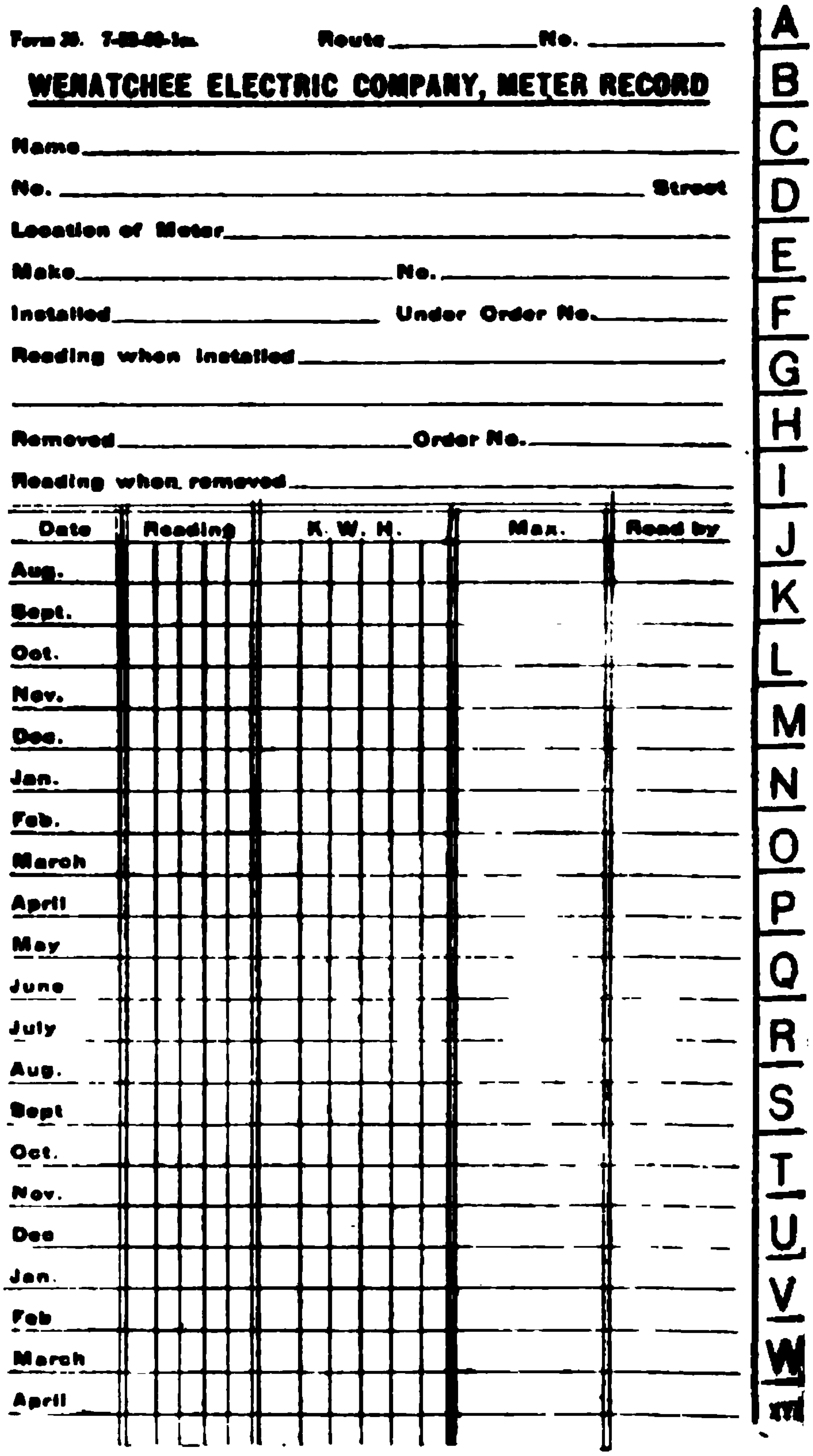


FIG. 354.—Form for Entering Register Readings of Watt-hour Meters, by the Positions of the Dial Hands. The semi-circles at the edge are punched out for the different routes, et cetera, and indicate when a card is misplaced.



Form 20. Route ______ No. ______

WENATCHEE ELECTRIC COMPANY, METER RECORD

Name ______

No. ______ Street

Location of Meter ______

Make ______ No. ______

Installed ______ Under Order No. ______

Reading when Installed ______

Removed ______ Order No. ______

Reading when removed ______

Date	Reading	K. W. H.	Max.	Read by
Aug.				
Sept.				
Oct.				
Nov.				
Dec.				
Jan.				
Feb.				
March				
April				
May				
June				
July				
Aug.				
Sept				
Oct.				
Nov.				
Dec				
Jan.				
Feb				
March				
April				

A B C D E F G H I J K L M N O P Q R S T U V W

FIG. 355.—Form for Entering Register Readings of Watt-hour Meters, in Figures. The cards are indexed by shearing off from the bottom all letters following the initial of the consumer.

reading can be made with more facility, the billing is somewhat expedited and the system is less cumbersome. The advantages claimed for the second method are that men less skilled can read the meters, and the readings furnish a complete record of the move-

ment of the dial hands, which, in the case of complaint originating on account of loose, or misplaced dial hands, may be of service in adjusting the matter. The first method meets with the most universal approval, and is used by the majority of companies.

Different styles of **printed forms for recording the register readings** are used (Figs. 354 to 358). It is usually customary to provide for each watt-hour meter a separate card or sheet, designed for one year's readings or more. It is preferable that they be not permanently bound in book form, as loose bound sheets can be arranged in the order in which the watt-hour meters are to be read, the sheets for any meters removed can be taken out of the binding and the sheets for any meters added can be inserted in their proper positions. When meters are disconnected but not removed, it is best to leave the sheets for these meters in the binding, so that the meters may receive periodical inspection. Some compute the kilowatt-hours on the same sheet referred to above, while others prefer not to do so, as there may be at times no record of the reading in the office.

It is considered advantageous to alternate the meter readers in the different routes or sections, so that no man reads the same route two months consecutively.

A desirable plan is to have each meter reader submit a daily report, which gives the elapsed time between reading the first and last meter that day, the number of meters read, and a list of any meters on the route not read, with the reason for omission.

The following method is used by one company: "The city is divided into sections, each book covering a section, and the meter readers receive 1¼ cents for each meter read."

Most of the later type of watt-hour meters read directly in kilowatt-hours, and are known as direct reading meters. The relative movement of the dial hands is in 10 to 1 ratio, so that a complete revolution of any one is equal to one-tenth of a revolution of the next slower moving dial hand or one division of the corresponding dial. The dial hands of adjacent dials turn in opposite directions.

Watt-hour meters which require, in order to obtain the required readings, that the dial reading be multiplied by a register constant other than unity are known as non-direct reading meters.

It will be noted by inspection of the accompanying illustrations of the various manufacturers' dial faces that a great variety exists in the markings, the number of dials and the arrangement of dials.

The desirability of the adoption of some standard dial face will be very apparent after a perusal of the various instruments for reading watt-hour meters, cited in this chapter (Chapter XVIII).

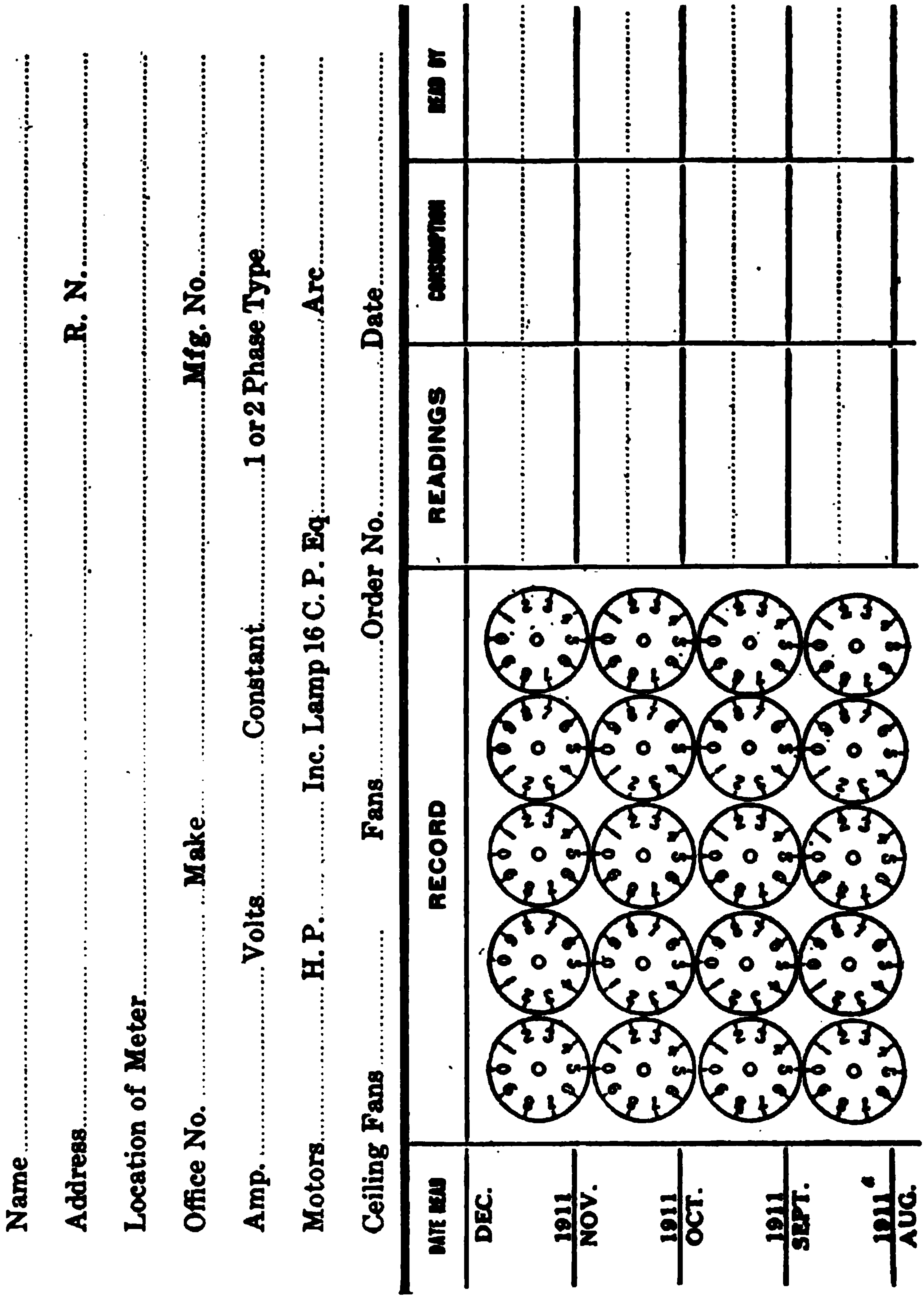
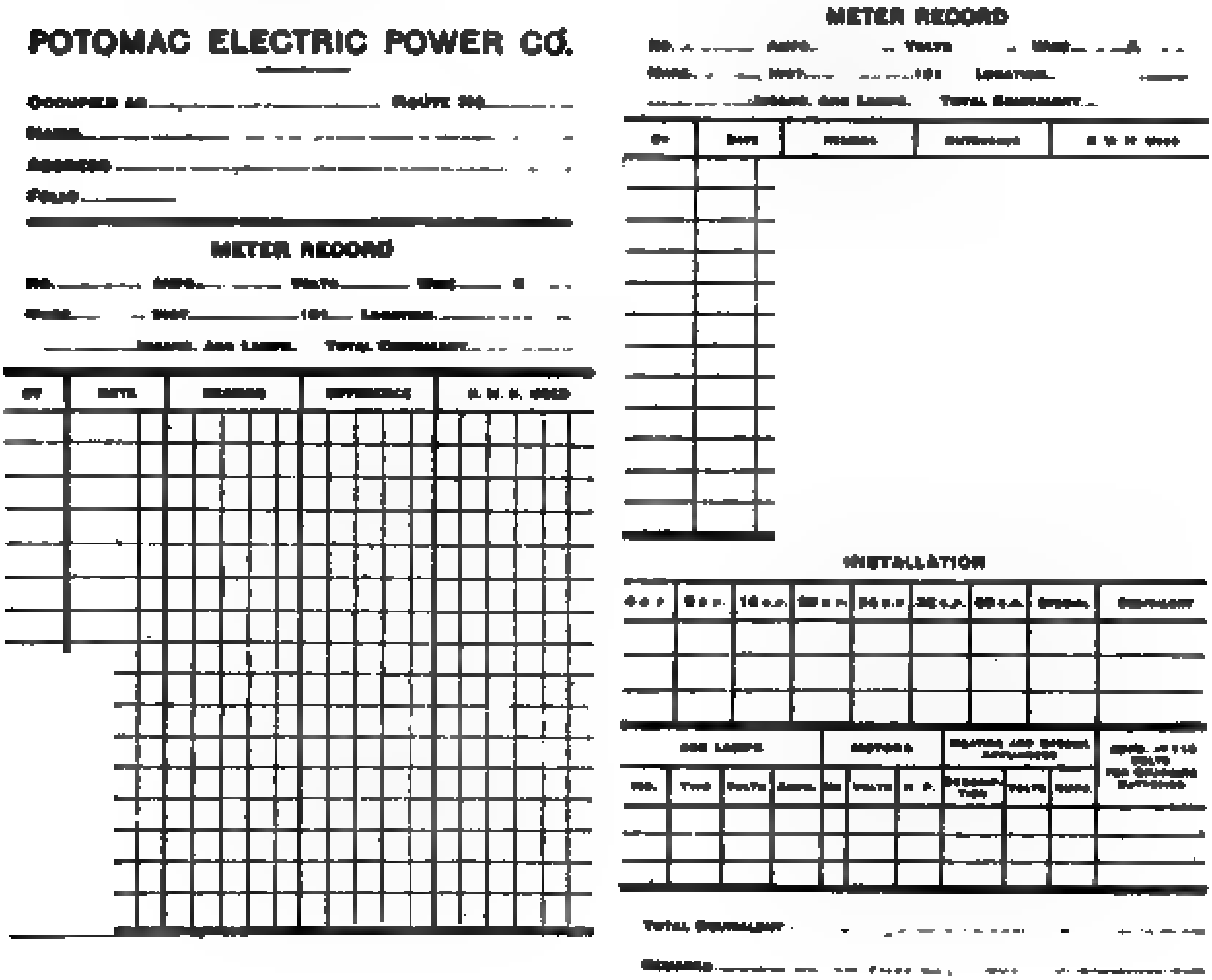


FIG. 356.—Form for Entering Register Readings of Watt-hour Meters, by Marking Positions of the Dial Hands.

It will be noted that many companies are removing the most rap-idly moving hand from the five dial meters, sometimes obliterating

this dial entirely by means of a red or black sticker or blank paper disk pasted over the dial.

To simplify the reading of meters having different values of one division of the first dial, one company has adopted a sticker, shown in Fig. 359, which is used to block out the first dial of all meters where one division is other than one kilowatt-hour. If one division of the first


POTOMAC ELECTRIC POWER CO.

METER RECORD

METER RECORD

INSTALLATION

FIG. 357.—Form for Entering Register Readings of Watt-hour Meters in Figures. Loose Leaf, Side Bound. Obverse and Reverse Sides.

dial is equal to 10 kilowatt-hours, the sticker as shown is used; and, as will be seen, its marking shows clearly the ciphers to add to obtain the desired reading. This sticker is colored red to bring it forcibly to the reader's attention. On meters where one division of the first dial equals 100 watt-hours, this same sticker, with reversed side out, which is blank, is used over the first dial, and the hand is removed. By this system, all readings are readily obtained in kilowatt-hours without the use of constants.

To obtain the register reading, it is necessary to note the value indicated by each dial hand, beginning with the first dial hand and writing the result from right to left. Owing to the close attention required, and the possibility of errors caused by the parallax, it is neces-

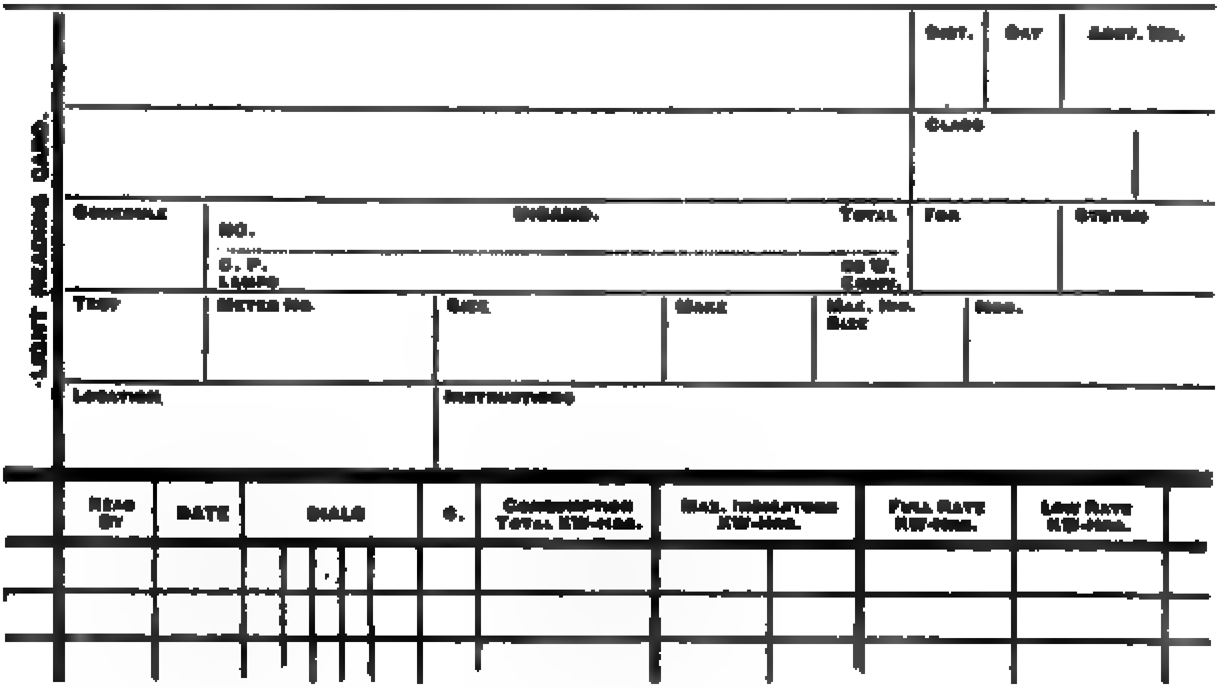


FIG. 358.—Form for Entering Register Reading of Watt-hour Meters in Figures. Loose Leaf, Side Bound.

sary to read each dial hand (except the first one) in connection with the one of the next higher speed of rotation. As a general rule it may be stated that when a dial hand stands between any two numbers on a dial, the lower number is read, unless there is a slight

FIG 359.—Paster for Altering the Value of the Divisions of the Right Hand Dial.

misplacement of the dial hand, which should be checked by reference to the next more rapidly moving dial hand, as just suggested.

As an assistance in explaining this possibility of reading the meter incorrectly, the analogy of the hands of a clock may be used. The

hour hand is never read on any hour until the minute hand has made its complete revolution, corresponding to that hour.

Under no circumstances should any register constant be used unless indicated on the meter dial face.

It should be the earnest endeavor to **instruct consumers** how to read their service watt-hour meters, and in the event of the reader being unable to gain access to the premises, an addressed return postal card may then be forwarded to the consumer, with the request that he mark the position of the dial hands on the facsimile of the dial plate printed on the postal card, and mail the postal card to the company.

The form used for this postal card and the success attained by one company by its use is indicated below (Figs. 360, 361 and 362):

Care should be taken that postal cards of this nature are made of a size not larger than allowed as first-class matter by the government, and, if a return portion is attached, it must be the governmental card with the one cent stamps imprinted on it in order to save postal difficulties and the labor of stamping.

Total number of postal cards sent out..........	2,681
Total number of postal cards which were returned "read" by consumers	1,137 or 42.4%
Total number of postal cards returned not "read," but stating when access could be obtained to apartment	501 or 18.7%
Total number of postal cards unaccounted for	1,043 or 38.9%
Total number of postal cards accounted for	1,638 or 61.1%

Where difficulty is experienced in reading because the occupants are absent, **further suggestions** are made:

1. That a time for reading be arranged with the consumer, either by letter, telephone, or return postal card, as suggested above.

2. That, in certain cases, a key be obtained and kept in the meter department, in which case the key should be numbered only, so that the consumer's name and address does not appear upon it. This will prevent trouble in case the key is lost.

3. That the minimum charge be billed month by month against such meters until the reading can be obtained, and a balance made at that time.

4. That a prepayment meter would be of advantage in such cases.

Various methods of presenting to the consumer's attention the

Dear Sir:

Our inspector has called at your premises several times to obtain a reading of the electricity meter, but has been unable to gain admission. Kindly notify us by telephone or by return card attached hereto when your meter can be read.

If an appointment cannot be made, and you will indicate the reading of your meter by filling in the position of the hands in the blank dials on attached postal card and mail to us, we will render you a bill therefrom subject to correction at our next reading.

COMMONWEALTH EDISON COMPANY.

METER DEPARTMENT.
Telephone Randolph 1280.

FIG. 360.—Return Postal Card.

instructions for reading his electricity meter have been devised by the different companies, some using cards attached to, or near, the meters, and others embodying them in a general handbook of information for the consumer. The latter method seems to be most popu-

FORM O M. 42

District .... Day .... Account No ....

Name ....

Address ....

Meter can be read on ....

....

....

CUSTOMER'S READING.

Leave left hand dial blank if meter has only four dials.

Meter No.

....

Date Read

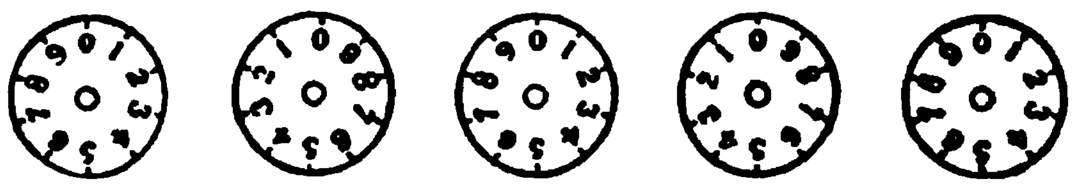


FIG. 361.—Return Postal Card. Return Portion.

lar, and examples of the text and presentation by both methods are cited below.

A thick card may be prepared with a hole at the top or other con-

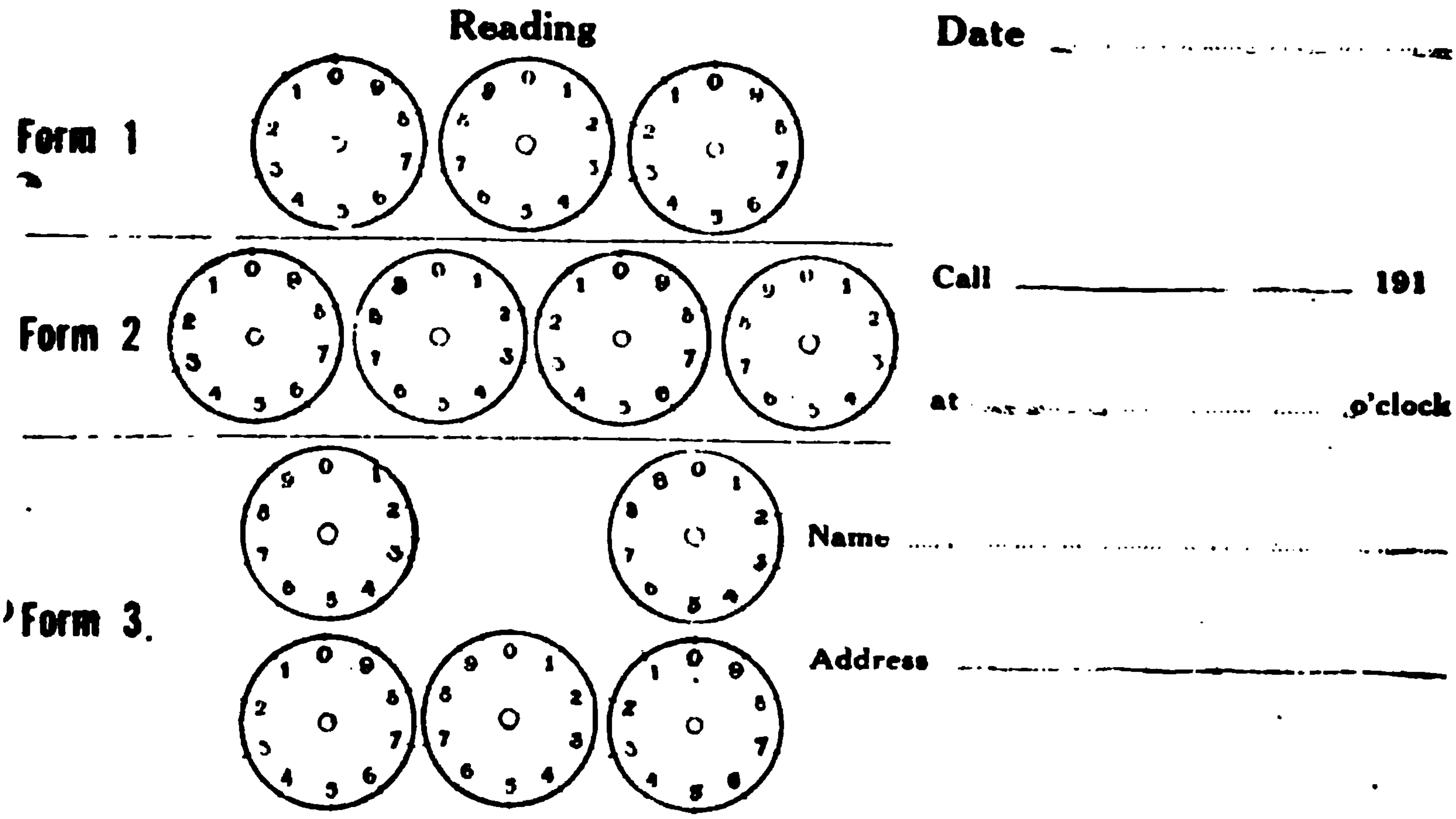


FIG. 362.—Return Postal Card. Return Portion.

venient means provided for the attachment in a conspicuous position at or near the meter, and with illustrations of the meter dials with instructions as follows:

HOW TO READ YOUR METER

This meter records the amount of electrical energy passing through it in kilowatt-hours (the unit of electrical measurement equal to 1,000 watt-hours). The above cuts represent the various styles of registering dials on electricity meters. Each division on the first right-hand dial carrying a dial hand represents one kilowatt-hour or unit. Starting with this dial hand, read each dial hand to the left in succession, placing the figures in the same order as read, being sure to take those figures which the dial hand has passed. If in doubt whether a dial hand has actually passed a figure, note whether or not the next dial hand to the right has just passed zero (0), remembering that no dial hand has completed a division until the dial hand next to the right has completed a revolution. The relatio between the speeds of all dial hands is 10 to 1; that is, one comple

revolution of one dial hand indicates one division on the next dial hand to the left. For uniformity the dial faces of all meters (of the same style) are the same without regard to capacity, so that in some sizes a multiplying factor called a register constant becomes necessary. This register constant is definitely established by the manufacturer of the electricity meter and is plainly indicated on the dial face as "Multiply by......" If two such constants appear on the dial face, always use the lesser one; if there is none, then the dials are "direct reading." To determine the number of kilowatt-hours, or units used, deduct "previous meter reading" from "present meter reading" and multiply difference by "register constant," if any.

Learn to read your meter and compare the "present reading," as given on your bill with the register reading at time of receiving bills.

Some of the presentations of instructions as issued in consumers' handbooks will now be given, which may be used as a basis for similar handbooks or as examples for the instruction of meter readers.

Instructions as applied to various types of watt-hour meters are given below:

"The following directions should be carefully followed:

"The dial hand on the right-hand dial of a five-dial meter registers one-tenth of a kilowatt-hour, or 100 watt-hours, for each division of the dial. A complete revolution of the dial hand of this dial will move the dial hand of the second dial one division and register one kilowatt-hour, or 1,000 watt-hours. A complete revolution of the dial hand of the second dial will move the third dial hand one division and register 10 kilowatt-hours, or 10,000 watt-hours, and so on. Accordingly, read the dial hands from left to right and add two ciphers to the reading of the lowest dial to obtain the register reading of the meter in watt-hours. Where there are four dials on the meter, the dial hand on the right-hand dial registers one kilowatt-hour, or 1,000 watt-hours, for each division of the dial, and it is necessary to add three ciphers to the reading of the lowest dial to obtain the register reading in watt-hours, or the meter reads directly in kilowatt-hours. The dial hands should always be read as indicating the figure which they have last passed, and not the one to which they are nearest. Thus, if a dial hand is very close to a figure, whether it has passed this figure or not, must be determined from the next lower dial. If the dial hand of the lower dial has just completed a revolution, the dial hand of the higher dial has

passed the figure, but if the dial hand of the lower dial has not completed a revolution, the dial hand of the higher dial has not yet reached the figure, even though it may appear to have done so. When one dial hand is on 9, especial care must be taken that the dial hand of the next higher dial is not read too high, as it will appear to have reached the next number, but will not have done so until the dial hand at 9 has come to 0.

"The dial hands on adjacent dials revolve in opposite directions, therefore a reading should always be checked after being written down, as it is easy to mistake the direction of the rotation.

Fig. 363.—Reading 1,188,900 Watt-hours.

"To determine the consumption for a given time, subtract the register reading at the beginning of the period from the register reading at the end. Always observe if a register constant is marked at the bottom of the dial face. If so, the difference of the register readings must be multipled by this register constant to obtain the registration.

"It is the practice of the company to read all five-dial meters as four-dial meters, dropping the reading of the lowest dial and the two ciphers following it, so as to give all results in even kilowatt-hours. If, however, the meter has a register constant of 10 or multiple thereof, the reading of the lowest dial is still retained." (Figs. 363 to 366.)

Instructions as applied to Duncan Model A watt-hour meters are given below (Fig. 367).

"To correctly read the sum indicated on the dials by the dial hands of a kilowatt-hour meter, these instructions should be carefully followed:

"The values (1,000s, 100s, 10s, 1s, Tenths) over the dials refer to the divisions of the circle over which they stand.

"Therefore, a division on the dial to the extreme right indicates one, two, three or four Tenths of a kilowatt-hour, while a complete revolution of the dial hand would be 10 Tenths, or one kilowatt-hour, and will have moved the dial hand on the second dial one division (1 kilowatt-hour).

"Thus in reading Example No. 1, the indication on the first dial

Fig. 364.—Reading 1965.9 Kilowatt-hours.

(that on the extreme right, or that with the most rapidly moving dial hand) indicates .1 (one-tenth); the next (1s), indicates 1; the next (10s), indicates 1; and next (100s), indicates 1, and the remaining dial (1,000s), also indicates 1, making the total register reading 1111.1, or a registration of 1111.1 kilowatt-hours. (See Chapter XV.)

"A dial hand to be read as having completed the division must be confirmed by the dial before it (to the right or the one with the next most rapidly moving dial hand). It has not completed the division on which it may appear to rest, unless the dial hand before it has reached or passed 0, or, in other words, completed a revolu-

tion. Therefore, it is always advisable to read dials from right to left.

"In reading Example No. 2, the indication on the first dial indicates .9 (nine-tenths). The second dial hand apparently rests on 0, but since the first rests only on .9, and has not yet completed its revolution, the second dial hand also indicates 9. This 9, placed before the 9 already obtained, gives 9.9. This is also true of the third dial. The second dial hand at 9 has not yet completed its

FIG. 365.—Reading 9,499 Kilowatt-hours.

revolution, so the third has not completed its division; therefore, another 9 is obtained, making 99.9. The same is true of dial four, thereby making the total registration 999.9 kilowatt-hours. When the dial hand on the first dial (extreme right) completes its revolution, or reaches 0, then the registration will be 1,000 kilowatt-hours.

"The dial hands are sometimes slightly misplaced. In Example No. 8 the first dial (the extreme right) reads 0 (no tenths). The hand of the second dial is misplaced. As the first indicates 0, the second should rest exactly on a division; therefore it should have

reached 8. The three remaining dial hands are correct and the entire reading represents a total registration of 9928.0 kilowatt-hours.

"In Example No. 9 the second dial hand is misplaced, for since the first indicates .1 (one-tenth), the second should have just passed a division. As it is near to 8, it should have just passed that figure. The remaining three dial hands are approximately correct. The total registration is 9918.1 kilowatt-hours.

"In Example No. 10 the second dial hand is slightly misplaced by being behind its correct position, but not enough to mislead the reading. The total registration is 9928.3 kilowatt-hours.

FIG 366 -Reading 8,889 Kilowatt-hours

"By carefully following these directions, little difficulty will be experienced in taking the dial reading, even when the dial hands become slightly misplaced.

"These registers read direct in kilowatt-hours (thousands of watt-hours), and as this is the unit upon which the rate of charge is based, it is obvious that no further multiplication is necessary.

"The following is an example of making out a bill on the kilowatt-hour basis. Suppose the register reading is 21.8 kilowatt-hours at 20 cents per kilowatt-hour, or per 1,000 watt-hours, which is the

same thing, the amount will be 21.8 × 20 cents = $4.36. If the rate is 16 cents, the amount will be 21.8 × 16 cents = $3.48. If the rate is 10 cents, the amount of the bill will be 21.8 × 10 cents = $2.18.

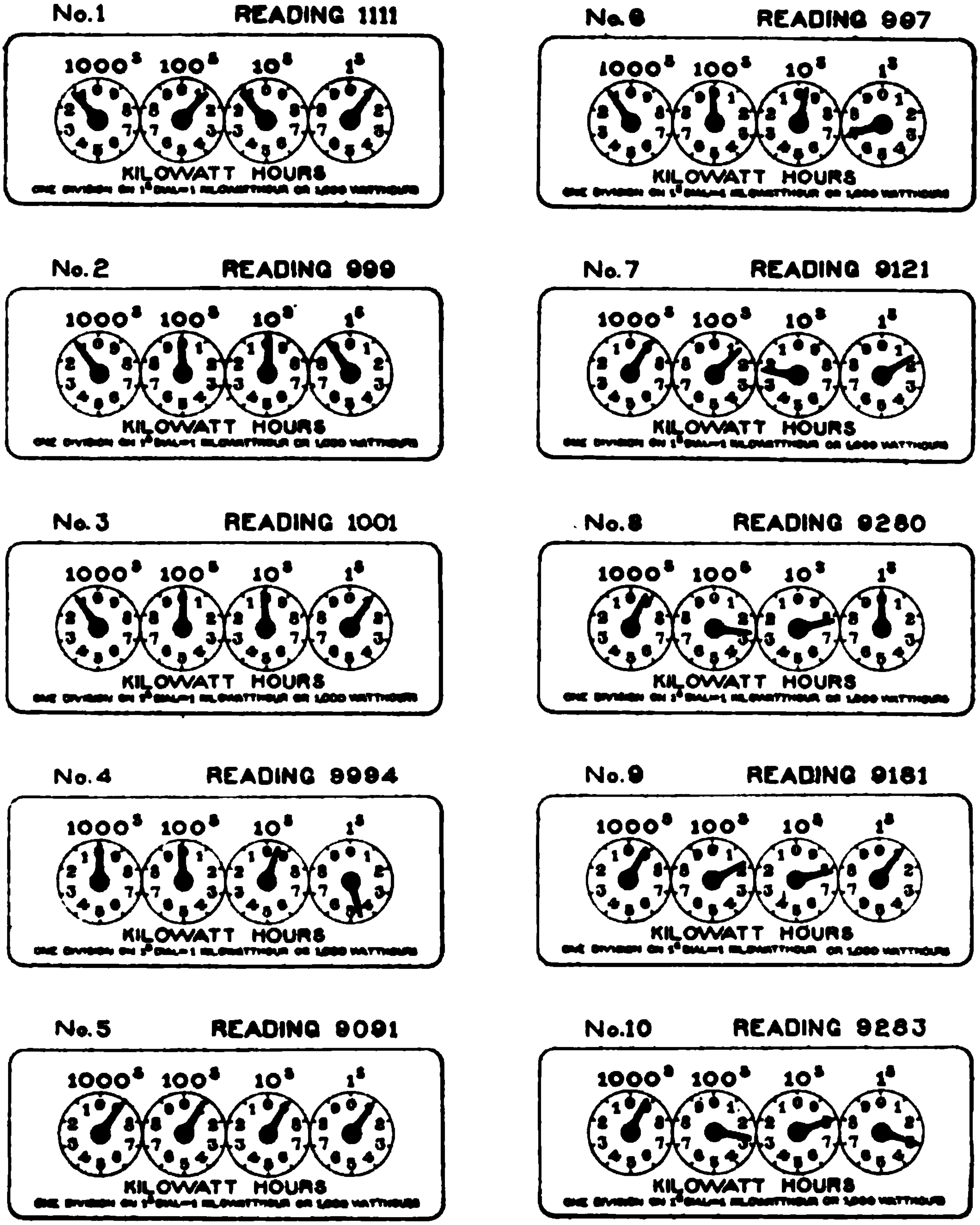


FIG. 367.

"If the dial face has 'MULTIPLY BY 10' marked on it, the register reading must be multiplied by 10. Example: Register reading 46.8 multiplied by 10 kilowatt-hours equals 468 kilowatt-hours."

Instructions as applied to Fort Wayne earlier Type K watt-hour meters are given below (Fig. 368).

"The dials of the meters for all capacities are direct reading, and record in kilowatt-hours (1,000 watt-hours).

"The figures (tenths 1s, 10s, 100s and 1,000s) placed over each dial represent the number of units registered by the passing of the dial hand from one number to the next. A complete revolution of the dial hand will produce a travel of one-tenth of a revolution on the next dial to the left.

"By referring to No. 1 it will be seen that the dial hand of dial marked tenths has passed over nine divisions, and as the value of each division is a tenth of a kilowatt-hour (100 watt-hours), the reading of the dial hand is 0.9 kilowatt-hours. The dial hand of dial marked 1s is pointing to 6, but as the dial hand of dial marked tenths

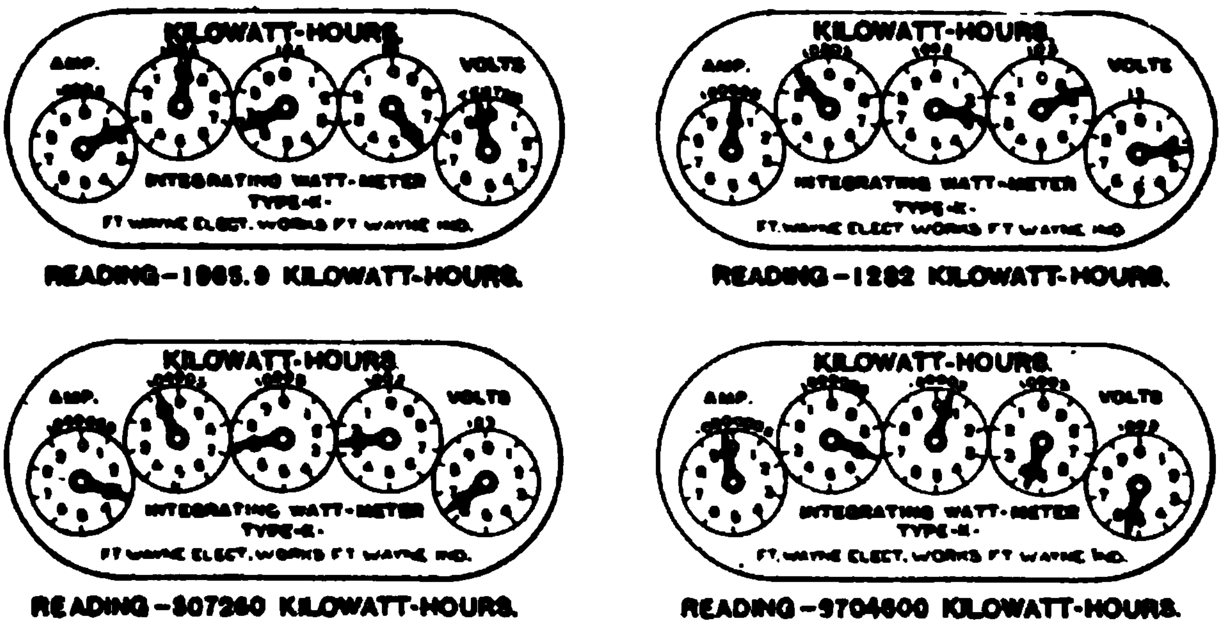


FIG. 368.

has not completed its revolution the dial hand of dial marked 1s has not reached or passed 6, hence its reading is 5 kilowatt-hours. The dial hand of the dial marked 10s is indicating between 6 and 7, hence its reading is 60 kilowatt-hours. The dial hand of dial marked 100s has nearly reached zero, but has not completed its revolution, as the dial hand of the dial marked 10s has passed but little over six-tenths of a revolution, hence the reading of dial hand marked 100s is 900 kilowatt-hours. The dial hand of the dial marked 1,000s is pointing to 2, but has not reached 2, as the dial hand of dial marked 100s has not completed its revolution, hence the reading of dial hand marked 1,000s is 1,000 kilowatt-hours.

"By adding the reading of the different dial hands we obtain the total 1,965.9 kilowatt-hours.

"By referring to Nos. 2, 3 and 4, which are given as examples, and by following carefully the same method of reading as given

above, we obtain from No. 2—1,282 kilowatt-hours; No. 3—307,260 kilowatt-hours and for No. 4—9,704,500 kilowatt-hours.

"In taking the register reading by the above method it will be noted that it is essential to consult the dial to the right in determining the correct position of the dial hand of the next dial to the left, hence it is advisable to read from right to left.

"By following carefully the directions as outlined no difficulty will be experienced in determining the correct reading of any meter. As no register constants are used on these watt-hour meters, the energy measured is read direct from the dial hands."

The following are instructions issued for the reading of one type of Westinghouse watt-hour register:

"In reading the upper register reading shown in Fig. 369, the first of unit dial is first read, the result being 1. The tens dial follows. The dial hand has passed the 8, but is near the division mark and a reference to the units dial shows that the dial hand has made one-tenth of a revolution since the tens dial hand reached the 8th division; the reading is therefore taken as 8, or a total of the two dials of 81.

"On the hundreds dial the dial hand is midway between 5 and 6. It cannot be read 6 until the dial hand on the tens dial has completed the revolution of which eight-tenths has been covered; consequently, the dial hand on the hundreds dial passed five last, and is so read, the total of the three dials being 581.

"On the thousands dial the dial hand is midway between 1 and 2, and will not read 2 until the dial hand on the hundreds dial traverses the remaining distance between 5 and 0. The reading is accordingly taken as 1, the total of all dials being 1,581, the total consumption registered, 1,581 kilowatt-hours.

"On the middle and lower registers it will be noted that the capacity is greater. In the middle register the dial on the right is the tens dial; therefore a zero is placed in units column and the lowest number—5—written in tens place. The other dials are read as previously explained. If desired a reading of units may be taken on tens dial as follows: Each division on the tens dial represents a consumption of 10 kilowatt-hours, and since the dial hand has passed over about six-tenths of one of these divisions, the figure six may be written in units place, or a reading of 56 kilowatt-hours for the tens dial.

"The necessity for reading each dial in conjunction with those of lesser capacity is shown in the lower register in which the dial hands of all dials are near or upon the division lines which indicate the number to be read."

Many companies, those selling electrical energy under a deman

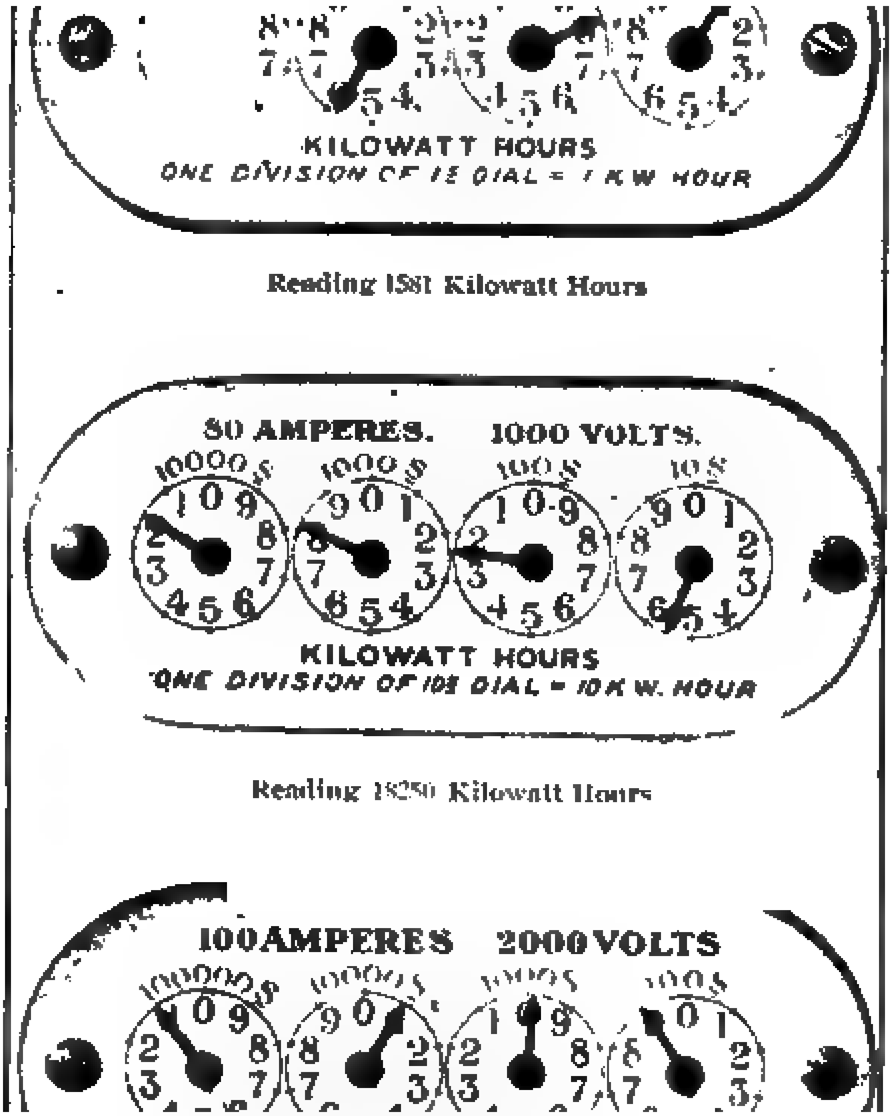

KILOWATT HOURS
ONE DIVISION OF 1S DIAL = 1 K.W. HOUR
Reading 1581 Kilowatt Hours
80 AMPERES. 1000 VOLTS.
KILOWATT HOURS
ONE DIVISION OF 10S DIAL = 10 K.W. HOUR
Reading 18250 Kilowatt Hours
100 AMPERES 2000 VOLTS

FIG. 369

and energy charge schedule, are of necessity using some form of maximum load indicator. (See Chapter XVII.)

The following instructions regarding the **reading of the maximum load indicators,** as issued by one company, may be utilized as suggested above in connection with the examples of instructions in reading of motor type, watt-hour meter registers (Fig. 370):

"The full, or demand, rate portion of the bill is determined by the readings of the maximum load indicators. These indicators have a

Fig. 370.

double scale. The left-hand scale shows the maximum current used in amperes and the right-hand scale shows the kilowatt-hours for which the consumer must pay at full rate. The reading of the indicator is shown by the height of the liquid in the tube and is taken from the kilowatt-hour scale. This scale is computed for 115 volt circuits; accordingly, when the indicator is used on a 230 volt circuit, the reading must be doubled as marked at the bottom of the scales.

"After each monthly reading the indicator is opened and the tube tipped up until all the liquid flows out. If electricity is being used the liquid will flow back when the tube is turned down again until

it indicates the current on the meter; otherwise the tube will remain empty until electricity is used.

"Two indicators are installed on a three-wire circuit and the sum of the readings gives the full rate portion of the bill. If a bill is for more or less than a month, the reading is divided by 30, and the quotient multiplied by the number of days covered by the bill to obtain the full rate portion."

Full explanations of the methods of using the rate schedules in computing the bill are also usually included in the instructions to consumers, so that every facility may be at hand to afford him a check on his bill.

As stated in Chapter IV, where ampere-hour meters are used, the average voltage at which service has been supplied must be taken into consideration in computing the kilowatt-hours for the registration, and if the meter be of the electrolytic type the method of reading will, of course, be quite different from that of the motor type of electricity meter.

The Wisconsin Railroad Commission has formulated substantially the following, bearing on the **reading and registration of the electrolytic type of ampere-hour meter,** when used as a basis of charge for electrical energy.

"The particular type of meter which depends for its registration upon the fact that a quantity of water decomposed by the passage of an electric current is directly proportional to the ampere-hours passed, gives a registration which is proportional to the ampere-hours consumed rather than the watt-hours. In order to determine the watt-hours of energy actually used by the consumer the voltage maintained at the time the current is consumed must be known.

"The scale upon the meters of this type are labeled as reading kilowatt-hours and the schedule of rates is expressed in kilowatt-hours.

"From the construction of this type of meter it might appear that the meter might register when no current is flowing due to leakage or evaporation of the electrolyte. Since the electrolyte is carried in a glass jar there is very little danger of slight leaks taking place and the cracked or broken jars can be so easily detected that no special rule appears to be necessary in order to eliminate errors due to leakage.

"Each meter is provided with a lead cover and stopper to eliminate evaporation. It is necessary to place the oil film over the surface of the electrolyte and keep the stopper and cover on the meter whenever the meter is in service.

"In addition to leakage and evaporation, errors in registration of the type of meter under consideration may be due to the following causes:

irregularities in glass jars, incorrect scales, meter being overloaded, reading taken while bubbles are in electrolyte, and to difference between voltage supplied and voltage for which meter scale was made.

"Since the registration of the meter depends upon the difference in solution level in the glass jar it is necessary that the jar be fairly uniform in cross-sectional area and that the volume displaced between any given scale readings shall be correct within sufficiently narrow limits to keep the combined error within the requirements. This type of meter shall be tested by measuring the volume between various points upon the scale so as to give the accuracy in volume for each one-fourth of the scale.

"Whenever a meter of this type is read for the purpose of making a charge for electric service rendered, the current must be shut off for a time sufficient to allow all bubbles to pass off from the electrolyte and to allow the electrolyte to reach approximately room temperature before the meter is read.

"In order that the error in registration due to voltage variation may be determined and also that there may be full compliance with the law, voltage records shall be carefully taken in each locality at least once every three months or whenever changes are made, and proper correction shall be applied to all bills rendered.

"Although voltage records need not be taken at every consumer's cut-out, it is necessary that records be taken at enough services to give substantially the voltage conditions under which each meter is being operated. Furthermore, a station log shall be kept giving the readings of all indicating instruments on the station switchboard at least once every hour and oftener during the hours when the lighting load is changing rapidly. This, together with the construction records will serve as a check upon the changing of conditions requiring, or affecting, voltage surveys.

"The combined error in registration after applying the correction constant for voltage shall come within the limits prescribed. The correction constant for voltage should appear upon the consumer's bill together with the meter readings.

"In order to comply with the spirit of the rules in general it appears necessary to prescribe somewhat the practice to be employed in the refilling of the jars. Since all registration of previous consumption is entirely destroyed when one of these meters is refilled and since there is no way of checking the 'before filling' reading after the meter has been filled, it appears to be a reasonable requirement that the consumer be notified before refilling any meter. The electrolyte shall be free fror

bubbles and within 5 degrees Fahrenheit of room temperature when readings are taken both before and after refilling."

Meter readers should possess matured characteristics that will fit them for the responsibility placed upon them by the management by making them the company's representatives in its dealings with the consumers.

Honesty, integrity, loyalty, punctuality and agility are requisite to the satisfactory carrying out of the duties of the meterman.

The wearing of uniforms by the metermen affords an effective means of identification, and expedites ready access to a consumer's premises, at the same time tending to relieve the consumer of suspicion that the wrong man has been given entrance. The best means of identification, however, in each particular case should be found by mature consideration by the company; some definite and effective means being decided upon and utilized in every case. The wearing of uniforms has a tendency toward raising the standard of discipline by directly identifying the wearer with the public service corporation.

In order to minimize the number of mistakes made some companies use the merit and demerit system in some form or other among their meter readers, keeping individual records on such points as the number of meters read; the number of readings in error; the number of meters missed; the record of punctuality and attendance; the expense for carfare and incidentals incurred in reading and other items which may indicate a meterman's efficiency. This data can be largely accumulated through the daily report referred to above, and the results of the investigation into the relative efficiency of the various metermen should be given periodical publication, on the bulletin board, or through the medium of the company's publications, if they have them.

Errors in reading should be a very small fraction of a per cent—for example, one error in 1,000 readings. To eliminate errors, competent men thoroughly instructed in meter reading should be employed. All watt-hour meters should read directly in kilowatt-hours, without the use of constants other than 10, 100, et cetera, and as far as possible only one style of dial face should be used.

The number of meters it is possible to **read per day** varies according to the territory covered; the location of the meter, as in attic or cellar; the number of meters in the same premises, etc. The practice ranges from 100 minimum to 425 maximum with about 150 average.

The following indicates the proficiency attained by one company and that may be expected, where expert metermen are employed.

	Sept., 1911	Oct., 1911
Number of readings made	26,725	25,280
" " meter readers	6	6
Maximum number read per man per day	425	425
Total number of mistakes in meter readings	2	1

All meter readings should pass through the hands of a competent man whose duty it is to question any apparent increase or decrease

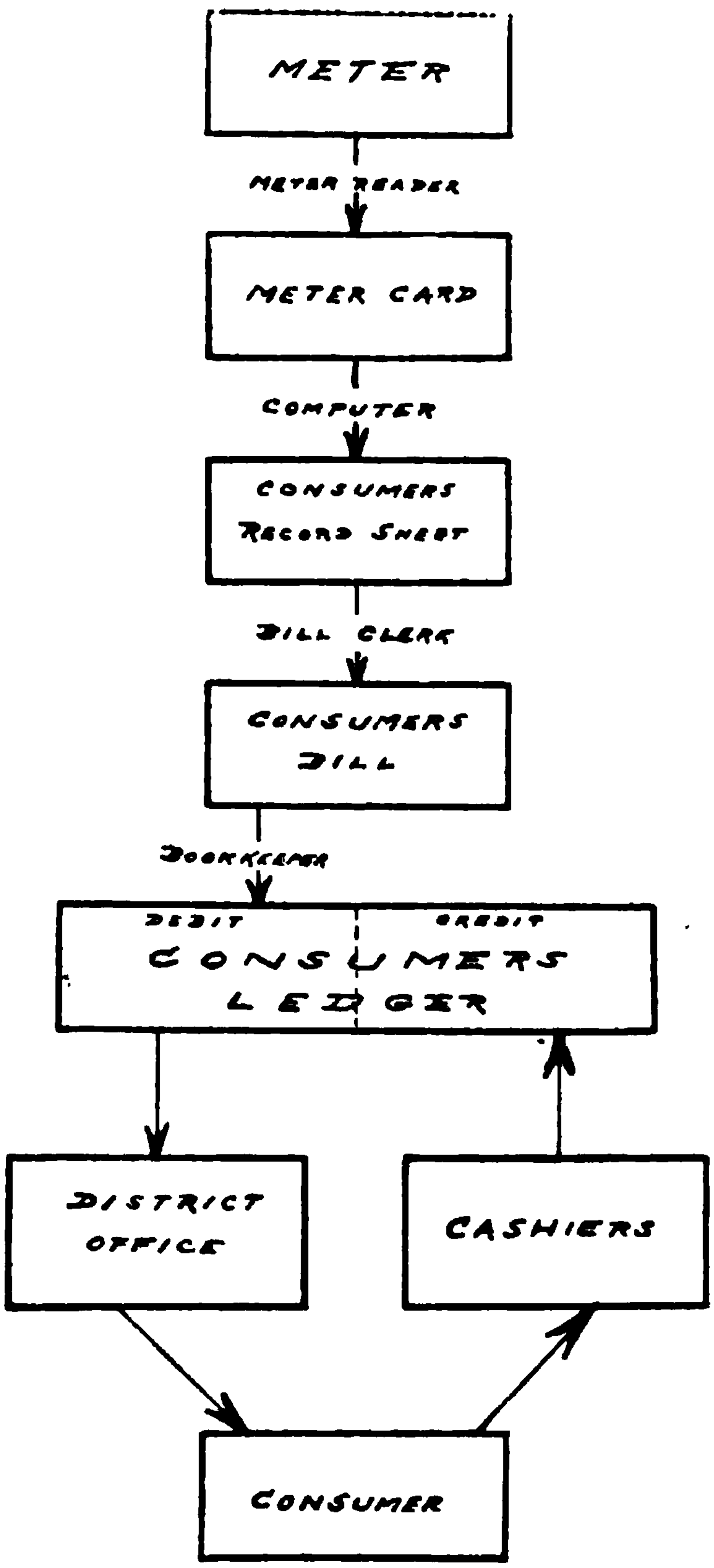


FIG. 371.—Watt-hour Meter Reading Routine.

in the consumption, and request **inquiry tests** where his judgment dicates their desirability.

The monthly watt-hour meter readings should be examined and all abnormal fluctuations in the registration from month to month should be investigated with a view to discovering errors in the meter, or other undesirable conditions. The registration will usually be subject to certain normal fluctuations, such for example, as an increase of consumption in winter. Such fluctuations are taken care of by applying a general knowledge of the conditions, and by comparing the registration with that during the same months of previous years.

Cases of high registration should be handled in a manner similar to complaints. (See Chapter XIII.)

In cases of low registration, the work done is only slightly different, the emphasis being placed on causes for real, or apparent, decrease in energy consumption, such as a defective or damaged meter, defective wiring, tampering, absence or removal of consumer from the premises, use of other illuminants; et cetera.

Meter readers are often educated and instructed to **make a superficial examination** of the meter, wiring, et cetera, and to report anything defective or irregular (Chapter XIII). In such cases, the meterman must make a full report of the wishes of the consumer, preferably on a blank form prepared for that purpose.

It is desirable where large consumptions of energy are registered each month, or where, for any other reason, a complaint might be anticipated, to have the consumer check the reading of the meter with the meterman, if this procedure is feasible, or in lieu thereof, to have the meterman leave a copy of the reading with the consumer so that he may check this reading before the bill is received. Either practice will facilitate the approval of bills by large consumers.

A suggestive diagram showing the routine followed in reading and billing a consumer's watt-hour meter registration is shown in Fig. 371.

CHAPTER XIII

INVESTIGATION OF CONSUMERS' COMPLAINTS

CHAPTER XIII

Investigation of Consumers' Complaints

No doubt every manager of a lighting company is convinced that, notwithstanding the care and attention he exercises in connection with his meter system, **complaints of alleged excessive charges** will always be made. With proper care and attention to his meters the manager is justified in having confidence in their accuracy, yet it

Table Showing Number of Hours Artificial Light is Needed in Each Month of the Year

Fig. 372.—Relative Amounts of Artificial Lighting Required During Different Months

is at times difficult to inspire the same confidence in the consumer, whose bill has increased apparently without sufficient cause.

The consumer frequently fails to take into consideration that the **increase in his bill may be the result of** longer hours of burning due to the season of the year (Fig. 372) or to social entertainments; carelessness of his employees; excess of cloudy weather (Fig. 373); defects in

his installation, and so forth, rather than to any inherent inaccuracy in the meter. It is decidedly impolitic, however, to ignore these complaints, and companies should spare no trouble or expense in order to satisfy the consumer of the accuracy of the bill; or, if errors exist in the computation, meter reading, or in the meter itself, to make proper restitution.

It is, in fact, believed that the number of complaints can be greatly reduced by an open and cooperative attitude, on the part of the company, in its contact with dissatisfied consumers. This com-

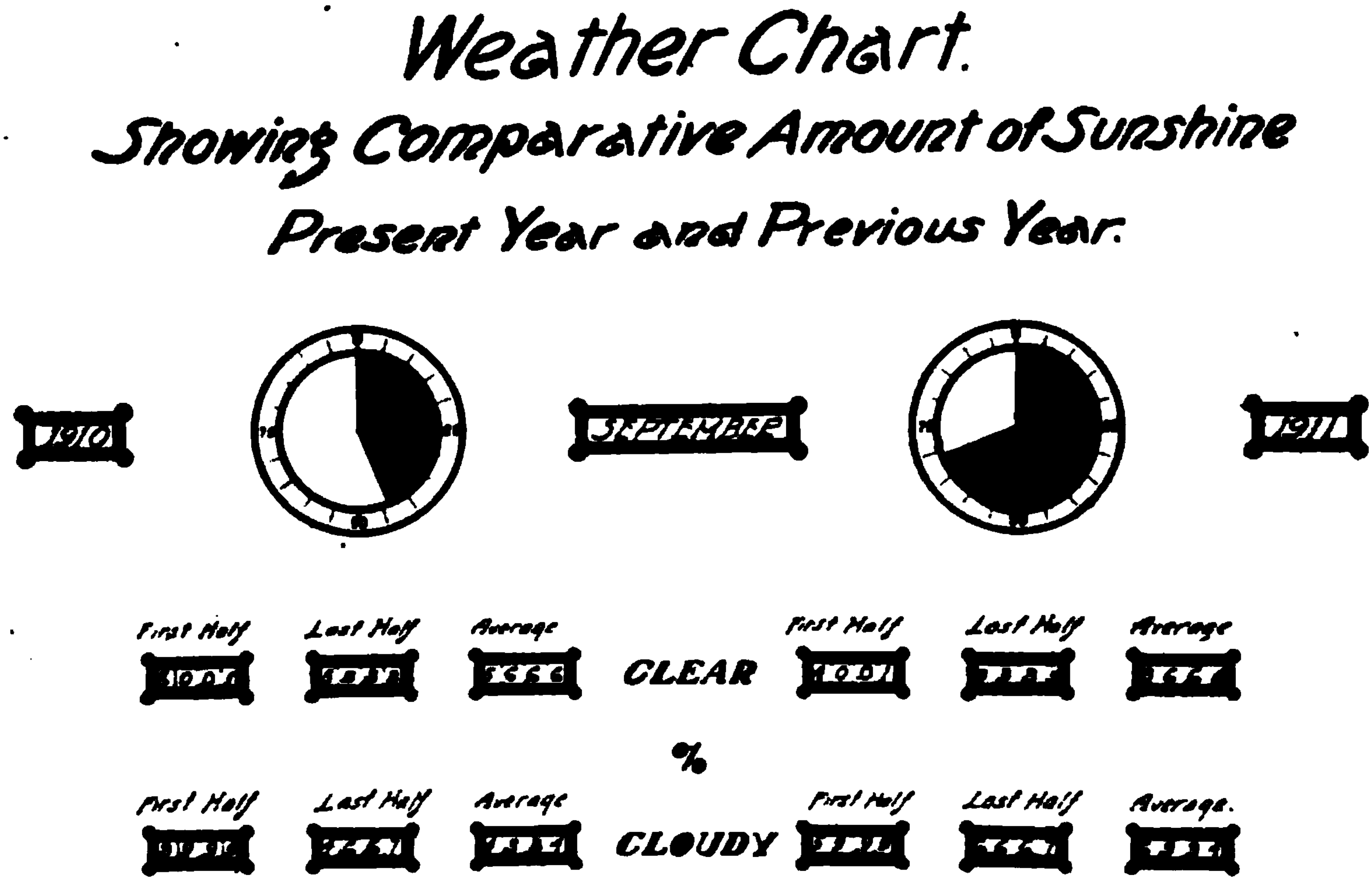


FIG. 373.—Weather Chart. Black and White Sectors are Adjustable. Other Spaces have Removable Cards to Allow for Replacement.

bined with a systematic effort to educate the consumer concerning the actual great reliability of electricity meters, resulting in the building up of the consumer's confidence in the measurement of energy utilized on his premises, will assist largely in minimizing the number of complaints.

Consumers' complaints, as the term implies, originate with the consumer himself, due to his interpretation of conditions surrounding the measurement of his consumption of energy as expressed to him on his bill, and may be based upon well-grounded reasons or upon ungrounded reasons for complaint.

Unless, as suggested above, the consumer has been imbued with

confidence in electricity meters, the complaint will be made on the general basis that the meter is inaccurate, and it will therefore require diplomatic and courteous investigation and straightforward explanation of the conditions actually found, in order to satisfy the consumer as to the accuracy of his meter and the fairness of the company's bill to him, or the equitability of the corrections proposed.

It should no more be assumed by the company that the consumer's complaint is based upon ungrounded reasons than it should be assumed by the consumer that his complaint is well grounded.

There are several **well-grounded reasons for complaint** that may arise, including inaccurate meters, electrical leaks on the consumer's premises, incorrect meter readings, use of wrong register constant in the computation of meter registration, clerical errors or similar items.

There are also many **ungrounded reasons for complaint,** which include the change of seasons; weather conditions; abnormal use for social reasons, on account of sickness or by irresponsible employees; increases in consumer's installation and other similar causes for increased use of energy.

From actual experience it can be said that more than 90 per cent of the consumers' complaints are found upon investigation to be ungrounded, but, as by no known instinct this point can be predetermined, it should always be the policy of the company to assume the consumer's complaint to be well grounded and investigate it thoroughly.

As the consumer is naturally the origin and the terminal of a complaint, it is undoubtedly the best policy for the company's original and final contact with the consumer to be through the medium of one department. The routine of the company should therefore be so established that all complaints will be lodged in one department, whether they originate spontaneously with the consumer, or are collected incidentally, or intentionally, from the consumer through the medium of the company's employees.

It is quite general practice to **receive all complaints in a department** of the company which may in some form, or other, constitute a commercial department. The contact with the consumer, both at the time of receiving the complaint and at the time of its settlement, should be made, in general, through this department. Complaints may be received by this department through voluntary personal interview with the consumer at the department; through efforts made under instructions, by certain selected employees to elicit construct

ive criticism from the consumer, for which purpose blank forms are sometimes used by such employees, or through routine methods of solicitation of this criticism by such means as correspondence and inquiries by metermen.

As has been already indicated, since complaints can be conceived

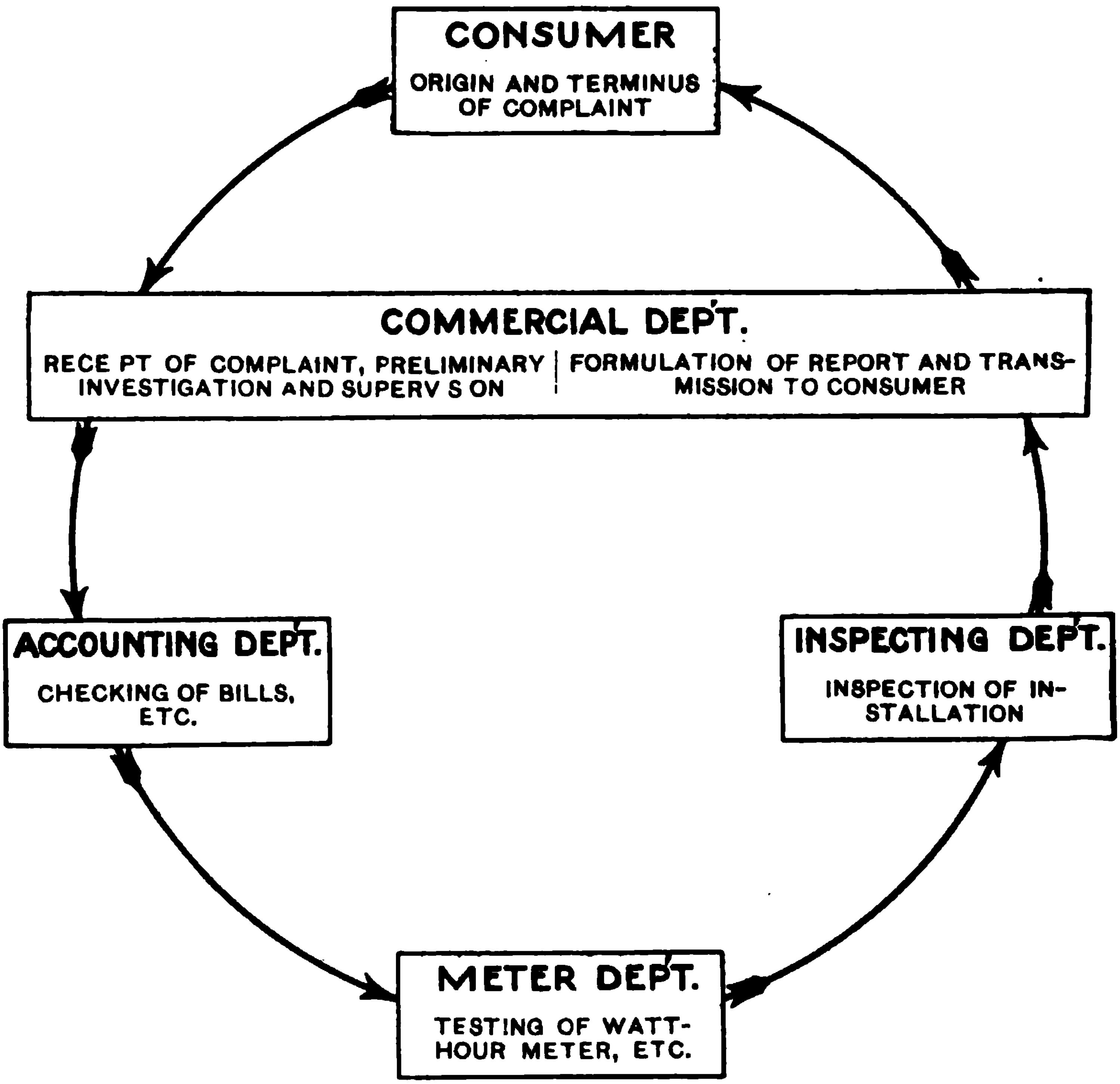


FIG. 374.—Suggestive Routine of Handling Complaints.

to originate and terminate with the consumer and to pass through the commercial department on its outgoing as well as its return trip, **the routine,** in its simplest form, **of handling complaints,** can be represented by a circular diagram, such as that shown in Fig. 374.

As indicated by this diagram, after whatever preliminary investigations may be conducted by the commercial department, the com-

plaint should be transmitted to the accounting department and meter department, according to an established procedure, which will naturally be largely governed by local conditions.

Concerning the handling of the complaint during the **personal interview with the consumer,** there is certain information and data which should be elicited from the consumer, while in contact with the commercial department, in order to settle the complaint without further investigation, if possible, or to be used in connection with such further investigation. A considerable number of complaints can usually be settled in this manner. This can frequently be done by having the consumer prove the accuracy of his own bill, by computing the wattage based on his own estimate of the lamps and hours used. The consumer's estimate often exceeds the amount of the bill, and he is thus convinced of its accuracy.

The consumer may be asked the following questions:

Do you understand the instructions issued regarding the reading of your meter and calculating your bill? (Chapter XII.)

Have you read your meter and estimated your bill?

Do you realize the difference in the darkness and cloudy weather prevailing during this month and the previous one? (Fig. 373.)

Have you not entertained more than usual this month?

Have you not accidentally left lights burning all night?

Have you used as much care as ordinarily in turning out your lights when not in use?

Have your employees used the energy without your knowledge?

Have you increased the size of any of your lighting units?

Have you used any heating utensils excessively?

Questions of this nature can be asked ad libitum, according to the judgment of the interrogator.

Other complaints require more **comprehensive investigation,** which must be continued until the cause of the increase is explained. In such cases an examination of the computations, readings, bills for the corresponding periods of the preceding year and similar items should be made. If no error exists in the calculations, or in the reading of the register, it is usually advisable to test the meter.

A large majority of the abnormal fluctuations in bills from which complaints and accounting department inquiries arise are due to causes outside the watt-hour meter. If records are kept, it will be found that 5 to 10 per cent of the complaints received are justifiable, in so far as clerical errors or errors in the meters themselves are concerned. It is therefore evident that, in order to explain the high bill to the satisfaction of the consumer, it is necessary in many case

that further investigations be made. Where the cause is discovered by inspection, and removed, no test on the meter is necessary, although to test the meter in such cases is a desirable precaution.

It may be considered by many that inasmuch as no error exists in the readings and computations, and the meter has been found accurate when last tested, the responsibility of the company ceases at this point, but from the viewpoint of good business policy and ethics it is advisable to go further. The method of investigation and adjustment should be systematized as much as possible in order to prevent delay in the payment of the bill.

The consumer is usually unfamiliar with electrical apparatus and is not possessed of the necessary instruments or knowledge to enable him to determine where the waste occurs, and is entirely unfamiliar with the many economies that the electric light company can often suggest to him. It is considered by some companies that no reasonable effort should be spared in an endeavor to prove to the consumer that not only are the bills as rendered by the company just, but that it is willing and desirous that the consumer avail himself of every legitimate means to reduce the kilowatt-hours consumed.

In the event, therefore, of non-adjustment in the commercial department, or if the complaint is made by letter or telephone, the matter should be turned over to a complaint adjuster. The adjuster, who may be an employee in the commercial department, or who may be a meter tester from the meter departments, where the complaint has been sent directly after the preliminary investigation in the commercial and accounting department, before calling upon the consumer should possess himself of the information already secured and outlined by the two above mentioned departments, and, in addition, make a notation of the meter statements on the bills. When the adjuster has the foregoing information, better results may be secured because he knows the relative gravity of the complaint, its exact nature, and he is prepared to check the bill, readings and consumption, and is enabled to conduct his investigation in an intelligent manner.

If the adjuster is a member of the commercial department and discovers the solution of the problem from an inspection, he should, of course, report back directly to the commercial department, and the complaint would not complete its circular route through the various departments, as shown in Fig. 374. The same would be true if the explanation had been found in the accounting department.

Likewise, the complaint may be returned one or more times from ne department to another, according to the circumstances of the

case, for additional information, the diagram being simply indicative of the simplest applicable routine.

It will therefore be assumed that the adjuster referred to above may be one or more persons, according to company routine, who should nevertheless be capable of investigating thoroughly all phases of the problem, until the correct solution is found.

The purpose of an investigation of this character is to effect a fair and amicable adjustment between the consumer and the company. As conditions vary in each case, no specific plan of procedure can be laid down. The following, however, will give a general idea of what is required.

The company should study the various problems connected with the **identification of its representatives,** and then furnish the most satisfactory means to every man who must come in contact with the consumers. The consumers should be urged to insist on the presentation of an identification before admitting employees to the premises in the company's name.

The following are some of the **means used for the identification,** at the consumer's premises, of the company's employees:

a. Badge.

b. Cap.

c. Complete uniform.

d. Identification card or letter, with or without photograph.

e. Exhibition of tools, instruments, meter reading book, or stating correct meter number from his knowledge of the records.

f. By consumer telephoning to company's main office for identification.

On entering the consumer's premises, he should make a superficial examination of the meter to see if it is running approximately correct; examine the conditions of the lamps and the distribution of candle-power, and endeavor to obtain the average usage of the lamps in order to estimate the consumption of current with which to compare the registration of the meter; for with this information he can often present to the consumer, arguments which will settle the complaint. In the hands of a competent man, a large proportion of the complaints can be settled without further delay.

Failure to do so, however, should insure a promise of further investigation, and the **complaint** may be **referred to the meter department** for action, with all bills, letters or written matter in connection therewith.

Meters should, therefore, be **tested on complaint** of the consumer:

(a) Whenever, after the elimination of other causes of dissatisfaction, it appears possible that the meter is at fault.

(b) Whenever, in the judgment of the company, a test is desirable.

A complaint test is a test made upon the premises where the watt-hour meter is installed, as a result of a complaint of the consumer.

The consumer, if he desires it, should be allowed to have a representative present to check the test at all points.

The **loads to be used in testing** should be chosen with a view to obtaining the best measure of the accuracy with which the meter registers the energy consumed. When the normal service loads cannot be determined, the method of testing at three loads and taking average accuracy may be used.

In general, the meter should be tested by **methods** described in Chapters VII and VIII.

It is the practice of some companies to replace the meter in the consumer's premises, bringing the old one to the shop or station, and there testing it.

The removal of the meter raises a doubt at once in the consumer's mind as to the accuracy and reliability of the results; and the mere fact of changing the meter lessens rather than increases his confidence in the new one.

Moreover, and most important, the operation of removal and installation of the meter is an expense needlessly incurred.

Watt-hour meters tested on consumers' premises give results under operative conditions with characteristics peculiar to each installation, whereas if removed they are tested under entirely different conditions with the added defects that are likely to arise through transportation.

If it is found necessary, on complaint tests, to change a watt-hour meter because of some defect which, however, does not affect the accuracy of the registration, it is advisable to delay the changing of the meter for several weeks, if possible; otherwise the consumer may consider that such change has a bearing on his bill.

First note the condition of the meter. Meter numbers, register readings and register constant should be carefully checked. Inspection should be made to discover broken seals or meter covers and discolored or charred dial face indicative of overloads. See that all dial hands are tight and in their correct relative positions and examine the gears to determine if any are loose on their shafts, et cetera. Make a dial test to determine whether the gear ratio is correct. This can be done by ascertaining from the watt-hour constant the

energy represented in one revolution of the disk, computing the number of revolutions necessary to cause the dial hand of the first dial to move over a given space, and causing the disk to make that number of revolutions, noting whether the dial hand moves over the space calculated that it should.

Particular inspection should be made with a view to ascertaining if the meter is **creeping.** If glass covers are used, so that the consumer can readily see the internal mechanism and ascertain that the watt-hour meter does not "run all the time," one cause of complaints may be eliminated.

After thorough inspection and tests of the consumer's watt-hour meter have been completed as suggested above, such **further investigations** should be made as are necessary to give the consumer satisfaction, either by discovering and correcting the error, or by demonstrating that the bill is a correct and fair charge for the energy delivered. While it is inadvisable to lay down fixed rules for such investigations, the following methods based on practice may serve as suggestions:

A tabulation of the installation; that is, a list of all the apparatus connected to the consumer's circuit with the continuous watt-rating of each may be made. The summation of these rated capacities gives the rated capacity of the installation.

An inquiry as to the hours of use of the various pieces of apparatus may be made, as an estimation of the probable energy consumption drawn up for comparison with the registration of the meter. A search should be made for causes of energy consumption unknown to the consumer, such as lamps left burning in out-of-the-way places; theft of current by third parties from the consumer's circuit; incorrect connections enabling another consumer to obtain energy through the meter under test. If meter is located in flat building, double house, office building or any place where the watt-hour meters are grouped, test should be made to see if meter is measuring the correct service, and that no service other than it is supposed to meter is connected to it.

The consumer is responsible for the condition of his wiring and should clear any defect thereon, and he is therefore responsible for the amount of current metered through such defect, but any apparent waste of energy should be noted, such as large lamps where small would do equally well, or unnecessary shafting, and the wiring should be tested for crosses, or grounds, through gas or water pipes, or otherwise. The endeavor should be not only to find the meter

accuracy, but to discover how the energy is being used, so that the consumer and the company may be thoroughly satisfied.

It is sometimes important to test the insulation of the consumer's circuit. This may be done in two ways:

(1) For total insulation resistance of the circuit and apparatus to ground.

(2) For the resistance between the wires when the consumer's load is disconnected.

The connections for the first test are shown in Fig. 375. For a two-wire installation, the same figure applies with the bottom wire omitted. All connections between the main line and the consumer's circuit are removed. Generally this is done by removing the fuses or opening the switch on the load side of the meter. The load wires (in the case of a three-wire circuit, the two outers and the neutral) are connected together, and a voltmeter is connected between the consumer's circuit and the ungrounded side of the service. If the neutral is grounded in the consumer's premises, this test will show zero resistance.

To test for insulation between wires, disconnect all the consumer's apparatus, remove the fuse from the ungrounded side of the circuit, leaving the fuse in the grounded side, and connect the voltmeter across the terminals where the fuse was removed. If the test is made on the service side, the voltage circuit of the meter must also be disconnected. On a three-wire circuit, this test would be made separately on each side.

With an ordinary portable voltmeter of high internal resistance, let R be the resistance of the voltmeter in ohms; X, the resistance to be measured; E, the reading of the voltmeter from the ungrounded side of the circuit to ground; E_1, the reading of the voltmeter when connected as shown in Fig. 375. Then $X = R\left(\frac{E}{E_1} - 1\right)$.

The facilities for natural lighting should be carefully considered. If the apartment is an interior one, obstructed by neighboring walls, it may be necessary to use electric light during many of the daylight hours, while their neighbors may not be required to do so. Or some one or two interior dark rooms may be used more extensively than other parts of the house.

The habits and customs of the occupants should be given due consideration—are they at home evenings or are they out much; do they use light only where it is needed, or do they light up to display the house; are they new consumers of electricity or have they been accustomed to its use; have they been accustomed to a flat rate or contract lighting, either in their former residence or in

their business place; have there been any weddings, sickness, deaths, parties, et cetera, or anything that would cause an increased consumption for the period in dispute.

The number and personnel of the household has much to do with the consumption; the more persons, the more lights will probably be used; young people, particularly of a society age, distribute themselves over the house more, and use more lights generally than do older people; students and roomers by their exclusive habits and longer hours are likely to use more current than others. If possible, the servants should be interviewed on the amount of light used in their apartments, and in the kitchen, cellar, et cetera, over which

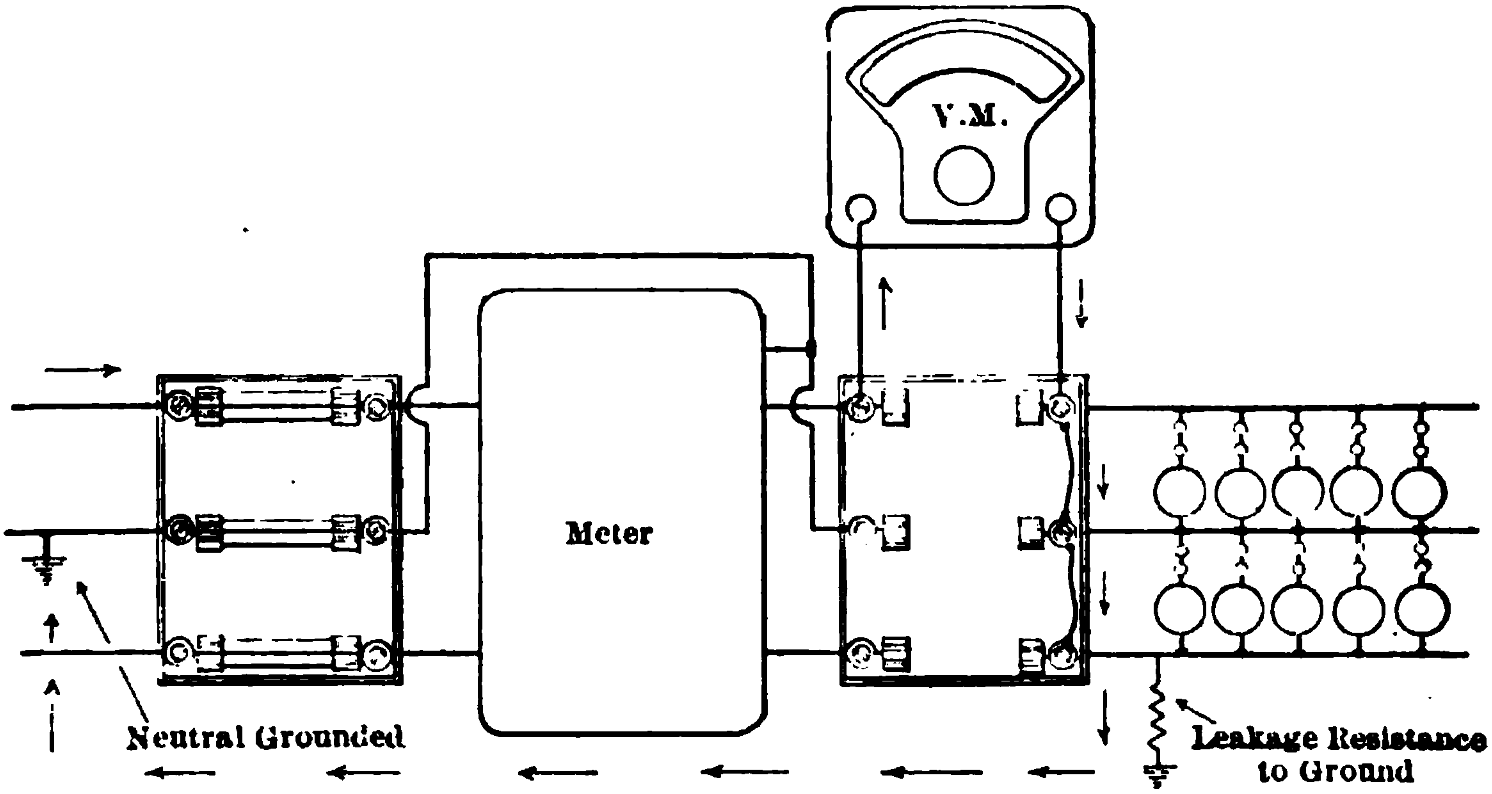


FIG. 375.—Diagram of Connections for Testing Consumer's Circuit for Grounds.

they preside. They are usually ignorant of the cost of electric energy, and are indifferent and extravagant in its use.

The distribution and size of the lamps is an important factor. Endeavor to have some responsible person familiar with the house interest themselves in the investigation, pointing out the number and size of lamps used in various rooms. Take note of the statements and at the same time make observations. By turning on the wall switch, throw on the lamps that are customarily used from that point of control, and it will often be found that a chandelier of lamps lights up, where the estimate is made that only one or two small lamps are used. When there are lamps on the third floor or in the basement, controlled from some other floor without the use of an indicating switch, it is often a source of much wasted light, and should be carefully looked into.

The character of the fixtures and glassware used should receive special attention. Lamps pointing upward, or at a sharp angle upward, do not furnish much illumination where it is wanted. A lamp in a high chandelier is not suited to library use. Lamps enclosed in opalescent or heavily frosted globes or in red tissue-paper shades lose much of their candle-power.

In many cases the complaint is not of a specific bill, but of the failure to derive benefits commensurate with the cost of the current. In addition to the foregoing, the condition and character of the lamp itself is an important element in such cases. The lamps may have fallen off in candle-power until more are required to give the desired illumination. A suggestion as to new lamps, metal filament lamps

FIG. 376.—Representation of Relative Amount of Light and Darkness During Different Months.

and the approved new high efficiency lamps would be apropos. Again, halls, bathrooms, bedrooms, closets, et cetera, do not require as much light as other parts of the house, and a suggestion to reduce the candle-power of the units in these places might be appreciated by the consumer.

The character and condition of the lamps is an important factor in commercial lighting In a large installation small loss in each unit may amount to considerable on the entire number. The lamps themselves may be old or the voltage low. The consumer may be using a large number of small units, distributed about the rooms to be lighted, where a few large units placed high would furnish a more suitable illumination for his purpose; besides these larger units properly installed are generally much more efficient.

Observe carefully the date on which the meter was last read and the time between readings. If the intervening time is greater than customary, it will have a corresponding influence on the amount of the bill. Then, again, the reading may have been delayed sufficiently to include in the last statement some unusual current consumption that the consumer thinks was included in a previous statement.

Business people are accustomed to compare the expense of one month with that of the corresponding month of the preceding year. By referring to the climatic conditions that have prevailed in the current months, the fallacy of such comparison may be pointed out. Rainy, foggy, cloudy and smoky weather increase the demand for artificial light. Use may be made of charts of relative darkness and light (Figs. 376 also 372 and 373).

By making inquiry, learn if any additions to the installation have been made during the period covered by the bill in question; if the person responsible for the consumption has been absent much during the period; if there has been any rush season to cause either motors or lamps to be used more than customary.

The recent installation of heating devices, electric irons, etc., should be investigated. Ammeter or wattmeter readings may be taken on motors, elevators, fans, heating devices, arc lamps, incandescent lamps other than standard make, or on steady loads, such as signs, window displays, and so forth; and information obtained as to the load and hours of use, et cetera.

In elevator service much loss is occasioned by inexperienced operators. If an elevator is not stopped when it is desired, the operator starts and stops it again, thus wasting energy.

The loads carried by an elevator have much to do with its consumption; also the manner in which it is operated. If an operator makes two or three trips to do the work that might be done in one trip, he is wasting energy.

A motor or controller may be wrongly connected, so that the shunt circuit is always closed; this would not readily be noticed by the consumer unless he should open the switch when the motor was not running—it would then be revealed by sparking at the switch.

The controller itself may be defective. Some types have a knife-blade contact that is operated by a spring which becomes weakened and allows the contact to break slowly, causing arcing.

The condition of the machinery has much to do with wasting energy. Bad bearings, loose bolts and lack of lubrication produce losses. The brushes of the motor should make good contact to pre-

may be attached to a line shaft (not otherwise required to run constantly) when an individual motor would do the work much more efficiently. Machines are often allowed to run when there is no need of them.

If no explanation of the high bill can be found many companies **install a graphic recording** ammeter, wattmeter or other curve-drawing **instrument**, which will not only prove to the consumer that the registration of the watt-hour meter is correct, but will also in many cases give the consumer information that will enable him to locate his losses. This form of test is very valuable in ascertaining exactly when and how the current is used, as such tests give in detail each change in amperes or watts of the load cut in or out for each minute of the day. (See Chapter XVII.)

These tests are usually made for an interval of from three days to one week, or longer if occasion demands. The charts are changed at a certain time each day; and, if necessary, the registration computed from the readings is also indicated.

If a graphic recording ammeter is used, and the wattage consumption is desired for the purpose of comparing the instrument readings with the registration of the watt-hour meter, it is advisable to ascertain the voltage several times during the test with a standard voltmeter, or else to install a graphic recording voltmeter, in order to convert the record of ampere-hours into watt-hours.

The statement of watt-hour meter must be taken at the beginning of the test, and also when each chart is changed, and again upon completion of the test, noting the register reading on the reverse side of the chart.

The expense of these tests—the expense depending on the degree of detail and the accuracy that may be required—is not prohibitive; and in the majority of cases the information required, which cannot be obtained otherwise, more than compensates for the outlay.

These tests are of peculiar value in obtaining data on the use of large installations, such as churches, offices, stores, manufacturing plants or large residences, where the consumer is unable to give personal supervision to the use of the current, and hence is unable to understand the alleged excessive charges of which he may complain.

It is in such cases that the graphic recording instrument is valuable in demonstrating to the user the abuse of current by janitors, servants, night watchmen, cleaners and employees in general; and, in addition to its assistance in settling the complaint satisfactorily, it ives information to the consumer for retrenchment in the use of

current at the point where he is not receiving value for the current used.

An approximate record can sometimes be obtained by counting the lamps, or apparatus, in use every half hour, or oftener, and plotting the results. Repeated visits on consecutive days may sometimes suffice.

The results of these tests and inspections should be put on the **complaint report** and the report **returned to the commercial department.** This report should be as complete and detailed as possible, so that satisfactory explanations in person or by correspondence can be transmitted to the consumer by the commercial department.

In case any of the many causes outside of the watt-hour meter itself have been found to be the reason for the complaint, **the method of settlement** is one merely of good business policy and judgment.

If the watt-hour meter has been found creeping, it should be timed with a stop watch and the rate of "creep," in watts, figured. The watts thus figured may then be subtracted from the watt-hour meter watts, as indicated by the tests on different loads. A set of percentage of accuracy figures is thus obtained, which can be averaged. The amount of "creep" in watt-hours can be figured on a 24-hour per day basis. Then the meter is reported as so many per cent fast or slow after deducting for this "creep."

EXAMPLE 1

Watt-hour meter tested and found to be as follows:

Creeping at rate of 1 rev. in 3 min., 10 sec., or 3.8 watts. It is a 5-ampere, 110-volt, continuous current, watt-hour meter.

	As Found	Deducting 3.8 Watts
½ ampere	110.0%	103.1%
1½ amperes	101.7%	99.4%
4 amperes	100.1%	99.2%

The meter is, therefore, practically accurate after deducting the "creep." Therefore, to make the registration of the watt-hour meter correct, an allowance of $3.8 \times 24 = 91.2$ watt-hours per day should be made.

The figures in second column are obtained as follows:

$$\tfrac{1}{2} \text{ ampere at } 110 \text{ volts} = 55 \text{ watts.}$$

$$\frac{(55 \times 1.10) - 3.8}{55} \times 100 = 103.1\%.$$

1.5 amperes at 110 volts = 165 watts.

$$\frac{(165 \times 1.017) - 3.8}{165} \times 100 = 99.4\%.$$

4 amperes at 110 volts = 440 watts.

$$\frac{(440 \times 1.001) - 3.8}{440} \times 100 = 99.2\%.$$

Example 2

Creeping at rate of 1 rev. in 2 min., 9.6 sec., or 6.9 watts. It is a 5 ampere, 110 volt, alternating current, watt-hour meter.

	As Found	Deducting 6.9 Watts
½ ampere	116.5%	103.9%
1½ amperes	107.6%	103.4%
5 amperes	102.5%	101.2%

After deducting "creep" it will be seen that meter is still about 3 per cent fast. Suppose that 31,200 watt-hours were registered by the meter in 30 days, the correct registration would then be—

$$\frac{31{,}200 - (6.9 \times 24 \times 30)}{1.03} = 25{,}468.$$

It will be seen that the registration was about 22.8 per cent high, whereas if the watt-hour meter had registered 150,000 watt-hours the registration would have been but 6.6 per cent high.

Thorough investigation of the causes of the creeping should be made as to whether they are external or due to a wrong adjustment of the meter; also as to whether the creeping of the meter is continuous or intermittent. Intermittent creeping may be caused by vibration due to machinery or street traffic, or to stray fields due to proximity of other electrical conductors or apparatus. In that case, correction for the creeping should be made only during those hours when the cause was operative. If a test of the meter shows that it is recording accurately otherwise, the correction for the creeping should be applied only to those hours when the cause was operative and no load was being used through the meter.

If the results of the tests indicate that the watt-hour meter is fast more than the allowable limit, it is only fair to the consumer that

he be given a rebate for the percentage overcharge. The allowable limit of inaccuracy in a watt-hour meter has been specified by civic commissions, where they exist, and is subject to the business policy of companies operating where no commissions are extant.

The rules affecting the operations of watt-hour meters formulated by some of the prominent civic commissions are quoted below.

The question of the time period over which this correction should operate is subject to some variation, according to the business judgment of the different companies, but it seems to be more or less common practice, where previous tests are available, to make allowance for excess registration for one-half the period since the last test, and when previous tests are not available, to place a limit on this period, and to allow rebates at the determined inaccuracy as far back as three months, or ninety days, from date of test.

An extract from an Ordinance of City of Chicago gives the following instructions:

"If the result of such test at such usual or such normal load shall show any meter to be incorrect as above defined, it shall be presumed that such meter was in the same condition and incorrect to the same degree for a period of not to exceed ninety days prior to the date of such inspection or test.

"Nothing herein contained, however, shall be held to preclude either the consumer, or the person, firm, or corporation owning, installing or using such meter from establishing by competent evidence the fact that meter was, or was not, incorrect for a longer or shorter period of time than ninety days prior to the date of such last inspection.

"Where the result of such inspection shows that the meter so inspected is incorrect, as herein defined, and such incorrectness shall operate to the disadvantage of the consumer by causing to be registered a greater amount of electricity than actually flowed or passed through such meter, in such case such consumer shall be entitled to a rebate from the person, firm or corporation supplying him with electricity through such meter, such rebate to be based upon the assumption that the incorrect registration existed for a period of ninety days prior to the date of said inspection or test; Provided, however, that if the consumer shall be able to establish the fact that such condition existed for a longer period than said ninety days, or if the person, firm or corporation supplying said consumer shall be able to establish the fact that such condition did not exist for so long a period as ninety days, then and in either event, the consumer shall be entitled to a rebate for such period of time as it shall be

shown such meter registered a greater amount of electricity than actually passed through the same.

"If the result of the inspection of any meter shall show that such meter is incorrect, and that such incorrectness operated to the disadvantage of the person, firm or corporation, owning or using same by reason of such meter registering a smaller amount of electricity than actually passed through same, in such case such condition shall be presumed to have existed for a period of not to exceed ninety days prior to the date of such inspection, and such person, firm or corporation shall be entitled to charge the consumer an amount equal to what would have been charged had the meter registered correctly, said amount to be based upon the assumption that said meter registered incorrectly in the same degree for a period of not exceeding ninety days prior to the date of inspection. Provided, however, that if the person, firm or corporation supplying the electricity shall be able to establish the fact that such condition existed for a longer period than such ninety days, or if the consumer shall be able to establish the fact that such condition did not exist for so long a period as said ninety days, then and in either event, the person, firm or corporation supplying the electricity shall be entitled to charge said consumer for such deficiency during the time that said deficiency shall be shown to have existed."

Dr. C. H. Sharp says: "The allowable limits of variations of meters from absolute accuracy are usually defined in governmental statutes. An important practical question is that of giving a single figure to designate the **average accuracy of a watt-hour meter.** The error of a watt-hour meter usually being different at light load from what it is at full load, and having still other values at intermediate loads, it is difficult and embarrassing to answer inquiries from consumers as to what the accuracy of a particular meter is. Some companies have adopted the radical practice of giving as the error of the meter the maximum error found at either light or full load, and have based their consumers' rebates for fast meters on this figure, making the rebate on the assumption that the error had changed uniformly with the time zero at the time of its previous periodic test to the time it is found fast. In other words, the error as found is assumed to apply to one-half of the period elapsed since the last previous test of the meter. This system evidently gives a maximum of advantage to the consumer. For the purpose of **giving a single value to the accuracy of a meter,** the system of averaging loads which has been put into effect by the Public Service Commission of the State of New York, First District, is worthy of

loads; namely, light load, full load and normal load. The normal load of a meter as a percentage of its full load rating is determined by the character of the installation in accordance with the schedule referred to elsewhere.

"The average percentage of accuracy is obtained by assigning a weight of 3 to the percentage of accuracy at normal load and the weight of 1 each to the tests at light load and at full load.

"This system has been found in the practice of the companies operating under it to possess very many advantages. Not only does it give the single value required for designating the accuracy of a meter, but it bases this value on a system of weights given to the accuracy at different loads, which, when the weights are properly chosen, makes it a very fair method of fixing this accuracy with respect to the probable consumption which should be charged against the consumer. The additional labor involved in testing at three loads rather than two is practically a minor disadvantage of this system. Its chief disadvantage is that a very considerable inaccuracy, either at light or full load, or both, may be masked by the average value. For instance, a meter may be quite fast at full load, correspondingly slow at light load, and still qualify as an accurate meter under the above definition. Evidently other systems of averaging loads could be devised, each of which would have its advantages and its disadvantages."

The following are excerpts from the rules discussed above:

Rules of the Public Service Commission, First District, of New York

Rule 4. All tests shall be made with the meter in its permanent position on the consumer's premises and under actual operating conditions as regards voltage, frequency, temperature, stray fields and vibration.

Rule 5. Where shunts, series current transformers or potential transformers are used in connection with a meter, the meter shall be tested from the line side of such apparatus when the voltage does not exceed 600 volts.

Rule 6. In periodic tests where the line voltage exceeds 600 volts, the meter may be tested as a self-contained meter, and the ratio certificates of the transformers may be used in calculating the true line watts, provided said certificates are dated within the five years preceding the time the meter is tested.

Rule 9. All meters shall be adjusted so as to register with an error of not more than one per cent at 10 per cent load and at 100 per cent

load, and both of these adjustments shall be maintained in this condition as nearly as possible.

Rule 10. All meters, whenever possible, shall be tested at three loads: 10 per cent of the rated capacity of the meter, normal load, and 100 per cent of the rated capacity of the meter.

The average of these tests, obtained by multiplying the result of the test at normal load by three, adding the result of the tests at 10 per cent capacity and 100 per cent capacity and dividing the total by five, shall be deemed the condition of the meter, and such final average shall be reported to the Commission on the form prescribed by it.

Rule 11. In an installation where it is impossible to obtain a load of 10 per cent of the rated capacity or 100 per cent of the rated capacity of the meter, tests shall be made at the nearest obtainable loads to 10 per cent and 100 per cent of rated capacity of the meter and values given in the ratios as stated above.

Rule 12. The following classification, in percentage of installation, shall be used in determining normal test load:

CLASSIFICATION OF INSTALLATION TO BE USED IN TESTING METERS AT NORMAL LOAD

A.	Residence and apartment lighting	25%
B.	Elevator service	40%
C.	Factories (individual drive), churches and offices	45%
D.	Factories (shaft drive), theaters, clubs, entrances, hallways and general store lighting	60%
E.	Saloons, restaurants, pumps, air compressors, ice machines and moving picture theaters	70%
F.	Sign and window lighting and blowers	100%

When a meter is found to be connected to an installation consisting of two or more of the above classes of loads, the normal load used must be obtained by taking the average of the percentages for the classes so connected.

Rule 13. Three tests shall be made at each load at which the meter is tested, but should any two fail to agree within 1 per cent, additional tests shall be made until three results are obtained, which do not vary one from another more than 1 per cent.

This Commission has also ruled that an allowance will be made upon every meter that is tested upon complaint as to its accuracy and found to register more than 104 per cent of accuracy. The percentage upon which the allowance will be based will be the percentage which the meter is found to be fast, above 100 per cent of accuracy.

The term "average accuracy," in the following example, refers to the value determined according to the above rules.

Examples: (1) The method of computing the average accuracy is illustrated below.

Percentage of Accuracy at 10% of capacity,	95.5 × 1 =	95.5%
Percentage of Accuracy at normal load.	98.7 × 3 =	296.1%
Percentage of Accuracy at 100% of capacity.	99.6 × 1 =	99.6%
	5)	491.2

Average Accuracy = 98.2 (to nearest 0.1%)

(2) A watt-hour meter is connected in a circuit furnishing power to an elevator (Class B) and to a small pump (Class E).

Rated capacity of meter, 75 amperes at 240 volts = 18 kw. capacity of installation

Elevator, 35 horse power motor ....26.1 kw.
Pump, 2 horse power motor .... 1.5 kw.

Total ....27.6 kw.

Percentage for elevator (B) 40% of 26.1 kilowatts = 10.4 kilowatts.
Percentage for plump (E) 70% of 1.5 kilowatts = 1.0 kilowatts.

Normal load ....11.4 kilowatts.

"This load is equivalent to approximately 63 per cent of the watt-hour meter capacity."

The use of two points for determining the accuracy of a meter, if properly selected, would doubtless be equally as accurate as the use of three points, and, inasmuch as the meter can only be adjusted at two points, a test at other points is more or less superfluous. It has been suggested that by means of graphic recording instruments, characteristic average load curves might be obtained for different classes of consumers, and the duration of light load and full load conditions determined, as well as the average light load and the average full load used in per cent of meter capacity. From these curves also, the percentage of the consumption registered at the average light load and full load could be determined. The average accuracy of the meter could then be obtained by testing the meter at the average light and full loads determined for that class of consumers and combining the results with a weight assigned to each, corresponding to the percentage of the consumption registered at that load. The average light load and full load, as well as the ratio of combining

them, would be different for different classes of consumers, but it is believed that a comparatively small number of ratios would cover the field and give a more accurate method of determining the average meter accuracy, than any single rule which is made applicable to all cases.

The above referred to Chicago Ordinance provides in Section 814-C for a three-point test to determine that a meter is within the limits of accuracy, but Section 814-D, which covers the matter of rebates, provides for a single test for determining this rebate as follows:

"Whenever any meter shall be inspected or tested under the preceding section a test reading of such meter shall be made at its usual average load, if such load can be determined, and if such load cannot be determined, then it shall be tested at its 'normal load' as hereinafter fixed. If any such meter shall register to exceed four per cent (4%) above or below the working standard at the usual or 'normal load,' it shall be deemed incorrect for the purposes of this section."

In reporting the percentage of accuracy of the watt-hour meter to the complainant, and the resultant percentage rebate if any is due, it should be made plain to the consumer how that percentage operates on his bill. If the report states that his meter is 5 per cent fast, it seems to be usual and natural for the consumer to interpret this as entitling him to a five per cent discount on his bill, whereas it should be interpreted that the percentage of accuracy of his meter is 105 per cent and his correct bill is therefore his incorrect bill divided by the percentage of accuracy, or it could be stated in terms of an equivalent discount on his bill.

The simplest way of overcoming this difficulty is to calculate, from the percentage of accuracy of the watt-hour meter, the kilowatt-hours incorrectly registered, and then reduce it to the equivalent financial rebate, eliminating from the report any reference to percentage.

Unless this point is given consideration, however, in the company's report to the complainant, the case may be reopened, no matter how thorough the investigation, because the consumer cannot check his rebate.

If the cause of complaint in any way involves the theft of current, the gravity and delicacy of the situation must be appreciated by all concerned, and the most mature judgment used in obtaining the necessary evidence and in handling the case from the instant of the discovery of the theft to its conclusion. A hasty announcement, or decision, on this point by an employee, without sufficient evidence,

may not only place the company in an embarrassing position, but may prevent the possibility of the accumulation of further evidence. Each company should give this subject the gravest consideration and, with or without the cooperation of their claim or legal department, devise a method of dealing with this important topic.

If the cause of complaint is found to be the use of an incorrect register constant, a simple, lucid **explanation of the principle and action of this constant** and the reason for its existence will probably be required. This may be necessary also when the incorrect number of zeros have been used in connection with the register reading, which is equivalent to the use of an incorrect constant. The following will serve the above purpose.

The register constant is the factor used in conjunction with the register reading in order to ascertain the total amount of electrical energy that has passed through the meter.

Experience in designing watt-hour meters has demonstrated that in order to minimize the wear on the jewel and other parts of the meter, and thereby promote the life of those parts, the speed of the moving element should not be more than 50 revolutions per minute. For this reason, the moving elements of all capacities of meters of a given type are caused to revolve at practically the same full load speed, and therefore the amount of electrical energy causing one revolution of the moving element necessarily increases as the capacity.

Since this value varies as the capacity, it is therefore governed by the capacity of the meter, hence the gear ratio and the numerical value of one revolution of the first dial hand are the only remaining quantities which can be varied in order that the numerical value of the register constant may be kept the same for meters of different capacities.

In the design and construction of the register mechanism of meter, the manufacturers have kept the numerical value of the register constant unity for meters of ordinary capacity, by assigning the proper values to the divisions of the dials and giving the gear ratios such values that are consistent with efficient mechanical operation.

For high capacity meters the values necessary to be assigned to the divisions of the dials become too large and those to the gear ratios too small, in order that the numerical value of the register constant be unity; for such meters the numerical value of the register constant is increased to 10, 100 or 1,000, as may be necessary. Some of the older types required various other values, according to design.

The required explanation may include a terse reference to the principles of watt-hour meters, and material for this will be found in Chapter III.

The above investigations, it is assumed, have been made—and such is the usual policy of the companies—with an open-minded, cooperative attitude on their part, making, voluntarily, every effort to discover the injustice, if there be any. A report should, therefore, not be turned into the commercial department until the tester, or adjuster, feels that he has accounted for the complaint, and can give a clear statement of the case that may be understood by the department and the consumer. It may be that the commercial department will deem it advisable at times to return the complaint to other departments for more complete or satisfactory explanations. In case the consumer is not finally satisfied, or wishes **an independent check on the meter accuracy,** the civic commissions have provided for a **referee test** to be conducted by them at the request of the consumer.

In accordance with legislative laws of certain states, therefore, consumers have the right to demand that their meters be tested when desired, but the law also provides that where the meter is found registering within commercial accuracy (varying from 4 to 5 per cent of correct registration) the consumer shall pay the costs of such tests.

Excerpts exemplifying rules and regulations relative to electric service and electricity meter testing, as formulated by Civic Commissions follow:

Rules of the Railroad Commission of Wisconsin

Rule 14. No electric meter which registers upon "no-load" shall be placed in service or allowed to remain in service.

Rule 15. No electric meter shall be placed in service or allowed to remain in service which has an error of registration in excess of four per cent on light load, half load, or full load.

Rule 16. Each electric service meter shall be tested and adjusted for accuracy at the time of its installation.

Rule 17. Each electric service meter shall be tested at least once each year; the test to be made by comparing the meter while connected in its place of service with suitable standards, on light load, half load, and full load rate of operation.

Rule 18. A complete record shall be kept of all tests made on electric meters.

Rule 19. Each company supplying electrical energy shall provide itself

with suitable equipment for the testing of meters, and shall employ such methods as are approved by the Railroad Commission.

Rule 20. Each company supplying electrical energy shall make a test of the accuracy of a meter upon request of a consumer, provided such consumer does not make request for tests more frequently than once in six months. A report giving the results of such tests shall be made to the consumer, and a complete record of the same shall be kept on file in the office of the company.

Rule 21. Upon formal application of any consumer to the Railroad Commission, a test shall be made upon the consumer's meter by an inspector employed by the Railroad Commission, such test to be made as soon as practicable after the receipt of the application. For such test a fee of two dollars ($2.00) shall be paid by the consumer making application for the test if the meter is found to be slow or correct within the allowable limits, and by the company owning the meter if the meter is found to be fast beyond the allowable limit.

Rule 22. Each company supplying electrical energy shall maintain a record of all interruptions of service upon the entire system or major divisions of its system, and include in such record time, duration, and cause of each interruption.

Rule 23. Each company supplying electrical energy on constant potential systems shall adopt and maintain a standard average value of voltage as measured at any consumer's cut-out, which shall remain constant from day to day, and vary during any one day by an amount not more than six per cent of the minimum value.

Rule 24. Each company supplying electrical energy for incandescent illumination shall adopt and maintain some method of procedure which will insure periodic inspection of incandescent lamps to which current is supplied and under which the company will render its consumers assistance in securing incandescent lamps best adapted to the operation of the system. Each company shall submit to the Railroad Commission of Wisconsin the details of such method of procedure as it may adopt.

The fee established in the above Rule 21, is very nominal and is hardly equitable for all tests under varying conditions of meter capacities, amounts of bills, geographical distance from the State capital to the complainant and other features. The fact that such a check on the company is available at such a low price is, however, a strong moral influence, not only affecting the companies, but tending to restrict the too frequent requests for tests on trivial complaints; at least it appears that the Commission has received only approximately fifty requests to make tests of this character since the adoption of the rule.

The Chicago Ordinance provides as follows:

"**By whom fee to be paid.** If the result of an inspection or tests made under and in accordance with the provisions of this ordinance shall show any meter so inspected to be inaccurate or incorrect, as defined herein, on any test hereinbefore provided, and to be registering a greater amount of electricity than passes through the same, within the limits fixed herein, the amount advanced by the consumer requesting such inspection shall be forthwith returned to him, and such inspection or tests shall be made without cost or expense of any kind whatsoever to such consumer; and in such case the fee provided for such inspection or tests shall be charged to or paid by the person, firm or corporation installing or using the meter so found to be inaccurate or incorrect. If the result of such inspection or tests shall show such meter not to be registering a greater amount of electricity than passes through the same, within the limits fixed herein, the expense or cost of such inspection or tests shall be paid out of the fee required to be advanced by the consumer making the application for such inspection, and no part of the fee advanced shall in such case be returned to the applicant. The current consumed or used in making such inspection or tests shall not be charged to the account of such consumer.

"The inspection and tests herein provided for, to be made by the city electrician, shall be conclusive upon both the consumer making application for such inspection and tests and the person, firm or corporation furnishing, installing or using such meter.

"Fees. The following shall be the fees charged by the city electrician for the inspection or tests of electric meters operating on circuits of 600 volts or less, as provided for by Section 814 hereof, to wit:

Amperes, Rated Capacity	Fees
10 or less	$1.50
Over 10 but not more than 15	2.00
Over 15 but not more than 25	2.50
Over 25 but not more than 50	3.00
And for each additional 25 amperes or fraction thereof...	.50."

The New York Commission's charge for testing is as follows:

"For two or three wire watt-hour meters, operating on constant potential circuits of 600 volts, or less, of capacity of:

10 amperes or less	$1.50
Over 10 amperes but not more than 15 amperes	2.00

Over 15 amperes but not more than 25 amperes	2.50
Over 25 amperes but not more than 50 amperes	3.00
For each additional 25 amperes or fraction thereof	.50.

"The fee must accompany application for test, but if the results of test show that the meter is operated to the consumer's disadvantage (more than 4 per cent fast) the fee will be returned.

"The Department of Water Supply, Gas and Electricity requires a uniform deposit of $2.00 for each meter to be tested, which will be returned if the meter is found to exceed the limit of accuracy as defined by law (more than 4 per cent fast)."

The General Assembly of the State of Maryland in 1910 passed an act to create and establish a Public Service Commission, and the parts relating to meters are as follows:

"And be it further enacted, That if any consumer to whom a meter has been furnished shall request the Commission to inspect such meter, the Commission shall have the same inspected and tested; if the same, on being tested, shall be found to be 4 per cent, if an electric meter, defective or incorrect, to the prejudice of the consumer, the inspector shall order the gas or electric corporation forthwith to remove the same and to place instead thereof a correct meter, and the expense of such inspection and test shall be borne by the corporation; if the same, on being so tested, shall be found to be correct, the expense of such inspection and test shall be borne by the consumer. A uniform reasonable charge shall be fixed by the Commission for this service."

Of course, the companies, in nearly all cases, make similar tests free of charge.

The following gives data on the watt-hour meters tested on complaint by Public Service Commissions:

The Commission of the First District of New York tested, on complaint, the meters, the accuracy of which is shown in the following table:

Year	4% or More Fast	Within 4%	4% or More Slow	Meters Tested
1908	13.4%	74.9%	11.7%	239
1909	7.2%	82.9%	9.8%	925
1910	5.6%	88.6%	5.8%	637
1911	5.4%	90.0%	5.6%	609

The figures mean that the above percentage falls within the group specified. For example, in 1911, 90 per cent of all meters tested were

The Railroad Commission of Wisconsin gives the following data on watt-hour meter complaint tests. The average percentage of accuracy at different loads is as follows:

Year	No. Tested	Light Load	One-Half Load	Full Load
1910	11	89.7	92.3	92.9
1911	15	91.6	100.6	100.1

"Registering to the prejudice of the consumer, 3 meters in 1910; 5 in 1911.

"Did not register to the prejudice of the consumer, 8 meters in 1910; 10 in 1911."

Maximum registration to the prejudice of the consumer averaged 6 per cent fast in 1910; 6.4 per cent in 1911.

A set of blank **complaint forms** should be designed to assist in carrying out the routine of this feature of the business and to record the

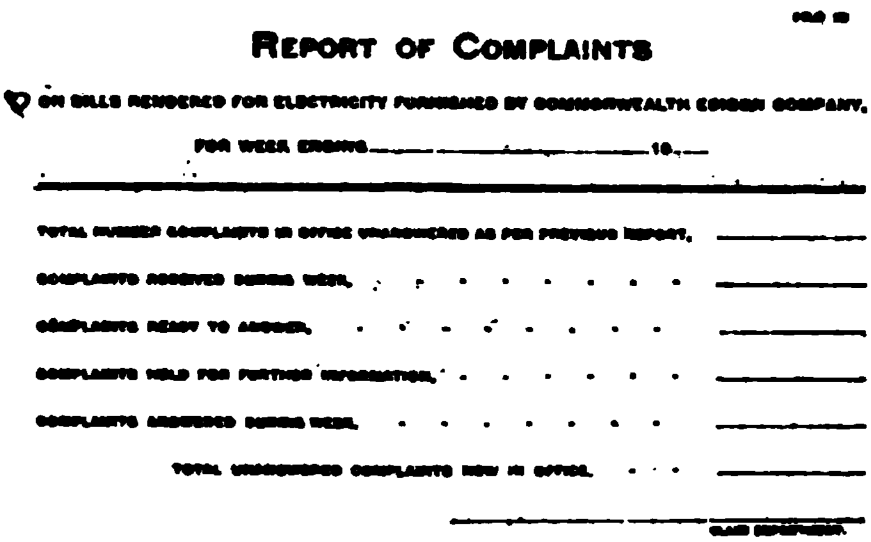

REPORT OF COMPLAINTS

FIG. 377.—Weekly Report of Complaints.

results. It is well to so keep the record that the name of consumer, address, date of receipt of complaint, date settled, complaint number, nature of complaint, results of investigation, nature of settlement and remarks, are made a matter of record.

The number of complaints received from any consumer can be determined, and the number of complaints investigated each month, and other data for monthly or special reports can be collected (Fig. 377).

The following are a few suggestions for these complaint forms: In one company (Fig. 378) when a consumer makes a complaint on a bill, it is made to the commercial department, who fill out a complaint form and forward it to the meter department. At the same time a carbon copy is retained in the commercial department as a follow-up record. A notice is also sent to the auditing department to waive penalty

department looks up the last test on the consumer's watt-hour meter, and if a very recent test has been made, the meter is re-read, and the

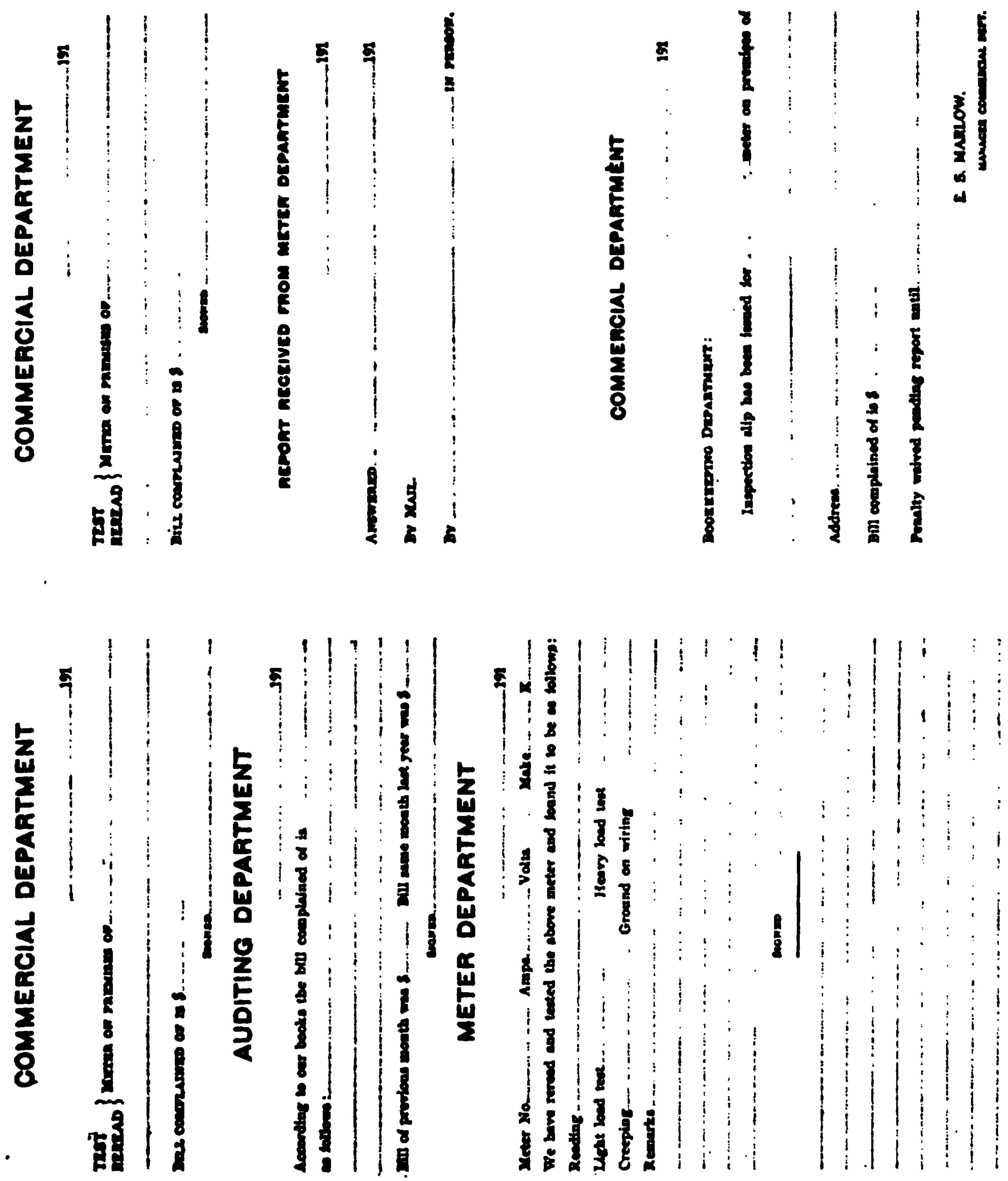


FIG. 378.—Forms for Handling of Consumers' Complaints.

result put on the form. If the meter has not been recently tested, a test is made.

While the tester is there he also tests for leaks or grounds in the

wiring, and for any cause that might cause an unusually large bill, as suggested in the earlier portions of the chapter. The results of

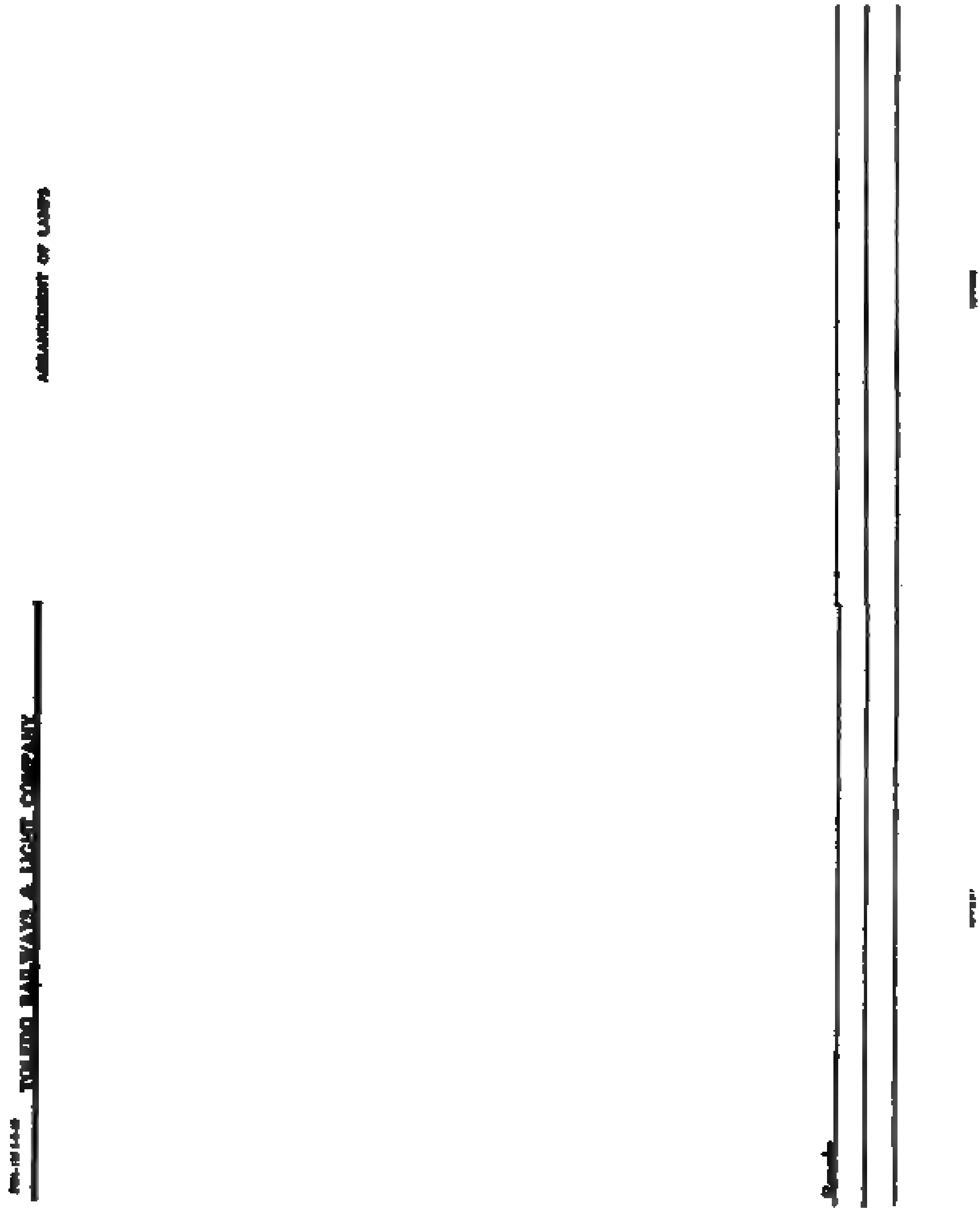


Fig. 379.—Form for Handling of Consumers' Complaints. Obverse and Reverse Sides.

this test and inspection are put on the complaint form, which is then ·turned to the commercial department, who check it on their follow-up

copy, and forward complaint to the auditing department. This latter department looks for errors in the reading of the meter, audits the bill and returns it to the commercial department, which in turn either writes a letter to the consumer or sends a representative of the company to explain the results of the investigation.

That part of the complaint form shown in Fig. 379, which is between

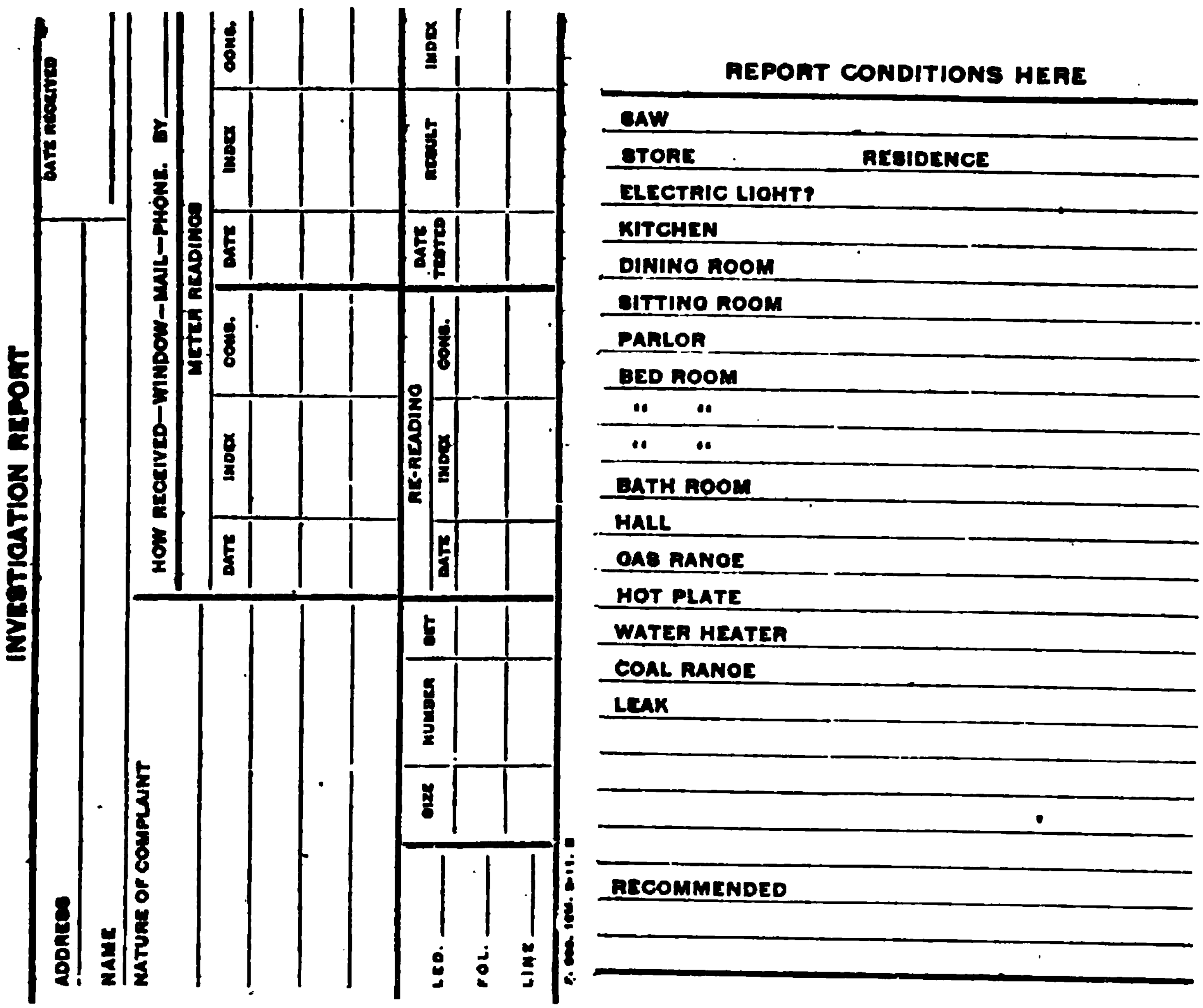


FIG. 380.—Form for Handling Consumers' Complaints. Obverse and Reverse Sides.

the first two double lines, is filled out by the commercial department, which receives the complaint from the consumer. Here are entered the meter number and register constant as shown by the bill, the readings, the kilowatt-hours consumed during the disputed period and the previous month's bill, with a brief general statement of the reasons the consumer gave for his complaint. This form is then sent to the meter department and follows an established routine similar to those above.

Fig. 380 shows the obverse and reverse sides respectively of a form used by another company.

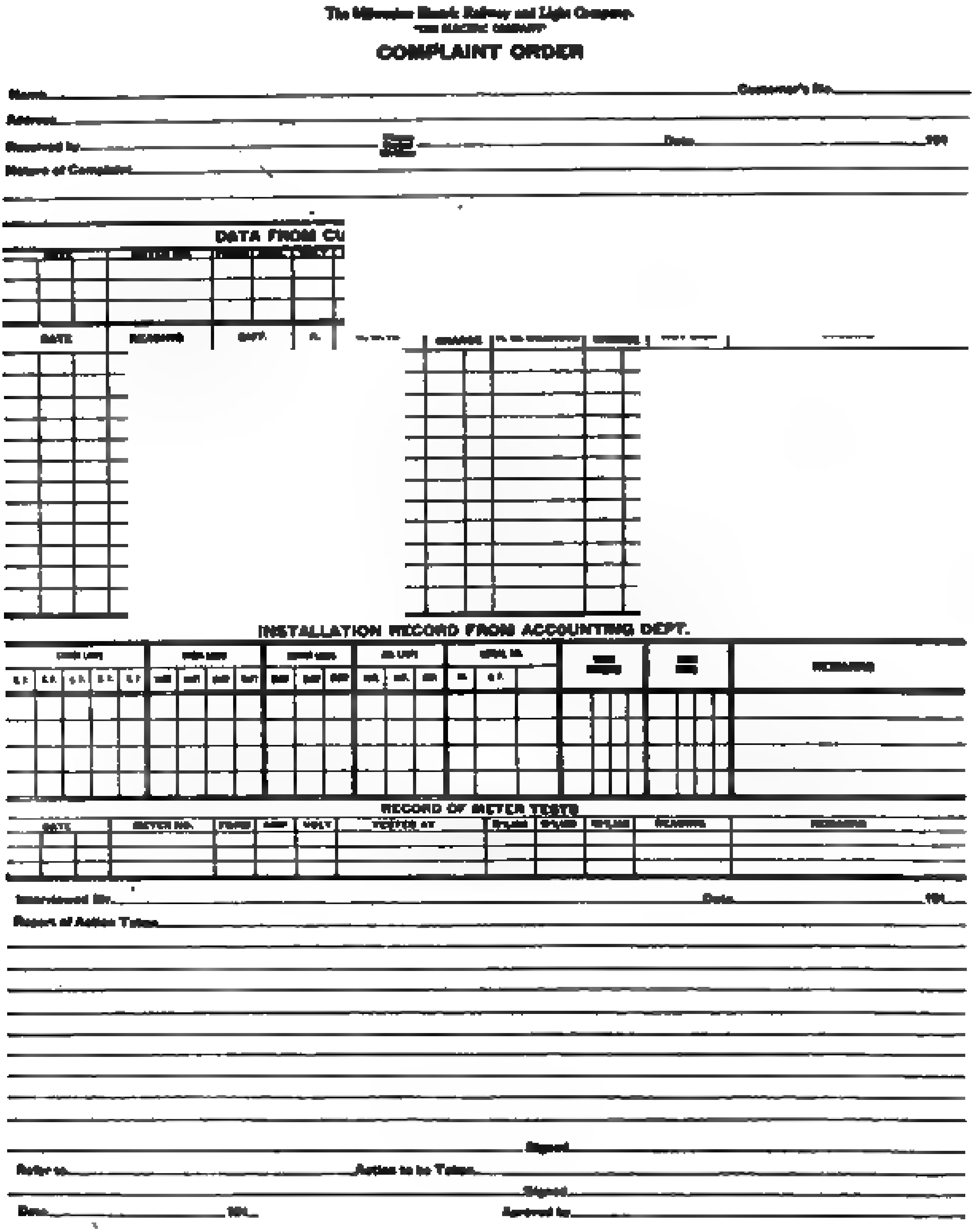
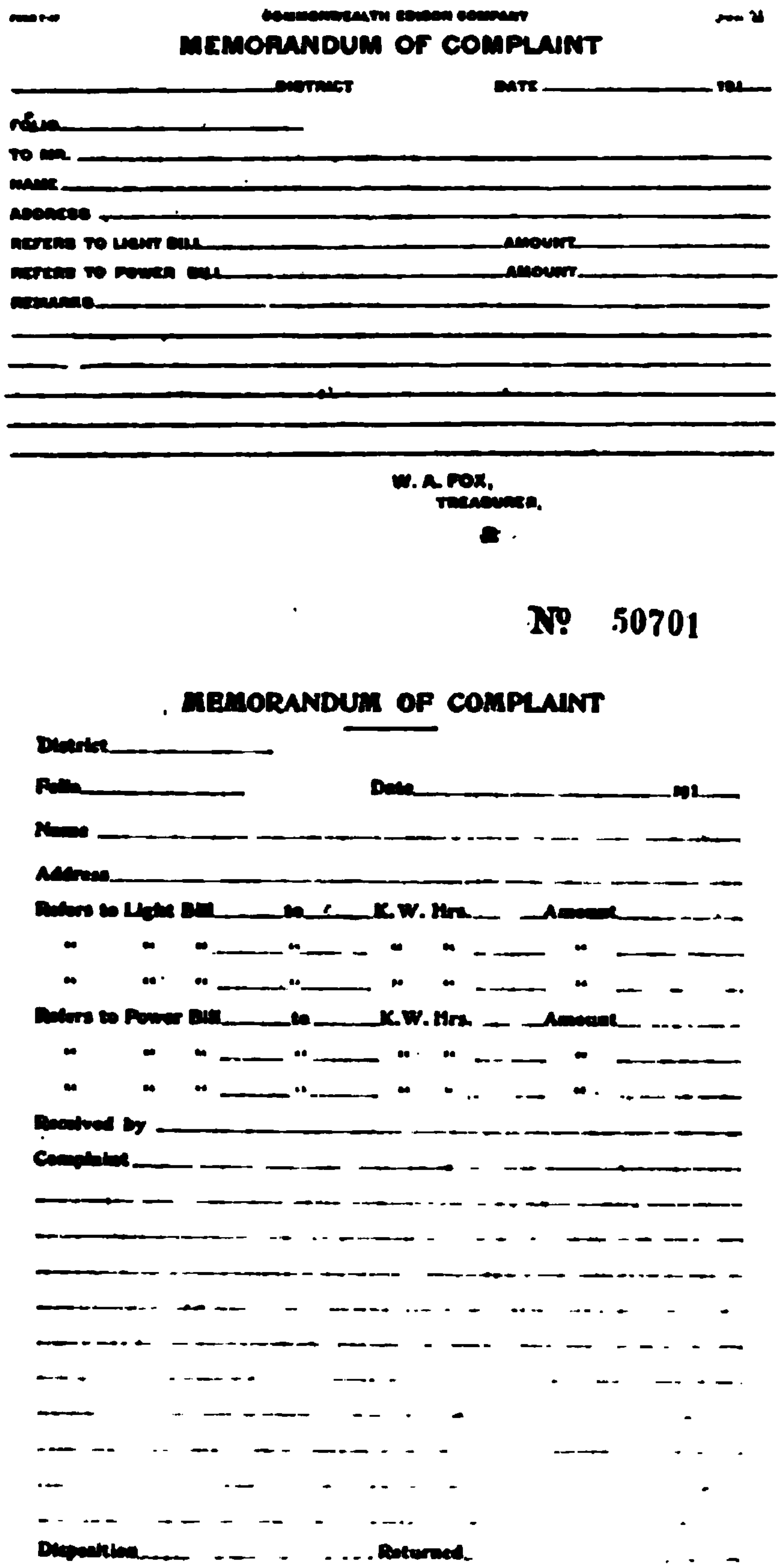


FIG. 381.—Form for Handling of Consumers' Complaints.

Still another form is shown in Fig. 381.

In another company the following complaint forms and methods are sed:

Form No. T 47 (Fig. 382) is the form used by the commercial department to notify the claim department of a complaint. The latter department fills out another form (Fig. 382) in triplicate, keeping a yellow


MEMORANDUM OF COMPLAINT
DISTRICT DATE 191
FOLIO
TO MR.
NAME
ADDRESS
REFERS TO LIGHT BILL AMOUNT
REFERS TO POWER BILL AMOUNT
REMARKS
W. A. FOX,
TREASURER.

№ 50701

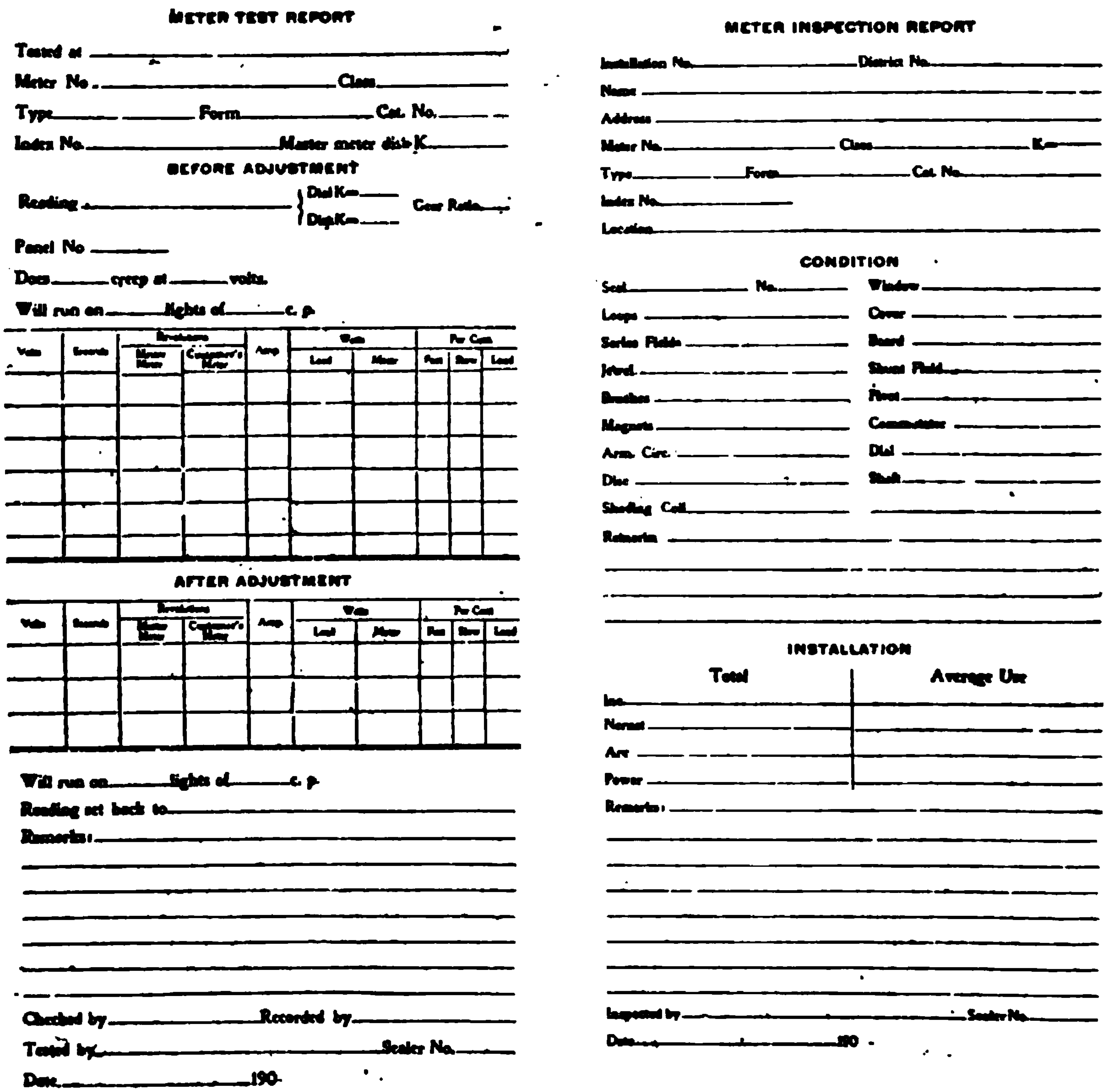
MEMORANDUM OF COMPLAINT
District
Folio Date 191
Name
Address
Refers to Light Bill to K. W. Hrs. Amount
Refers to Power Bill to K. W. Hrs. Amount
Received by
Complaint
Disposition Returned

FIG. 382.—Memoranda of Complaint.

copy until the settlement of complaint, when it is filed according to the number in the upper right-hand corner; sending a white copy to the meter department for the investigation, and sending a pink copy to the bookkeeper, who makes notation on the consumer's account that th

investigation is proceeding. The meter department may use the form in Fig. 383 in its investigation.

In conclusion, it is urged that the relation of the company to the consumer is the same as that of any producer to those who use his products. It is essential that this relationship be very close and



METER TEST REPORT

Tested at

Meter No. Class

Type Form Cat. No.

Index No. Master meter disk K

BEFORE ADJUSTMENT

Reading Dial K= Disk K= Gear Ratio

Panel No

Does creep at volts.

Will run on lights of c. p.

Volts	Seconds	Revolutions: Master Meter	Revolutions: Consumer's Meter	Amp.	Watts: Load	Watts: Meter	Per Cent: Fast	Per Cent: Slow	Per Cent: Load

AFTER ADJUSTMENT

Volts	Seconds	Revolutions: Master Meter	Revolutions: Consumer's Meter	Amp.	Watts: Load	Watts: Meter	Per Cent: Fast	Per Cent: Slow	Per Cent: Load

Will run on lights of c. p.

Reading set back to

Remarks:

Checked by Recorded by

Tested by Sealer No.

Date 190

METER INSPECTION REPORT

Installation No. District No.

Name

Address

Meter No. Class K=

Type Form Cat. No.

Index No.

Location

CONDITION

Seal No. Window

Loops Cover

Series Fields Board

Jewel Shunt Field

Brushes Pivot

Magnets Commutator

Arm. Circ. Dial

Disc Shaft

Shading Coil

Remarks

INSTALLATION

	Total	Average Use
Inc.		
Nernst		
Arc		
Power		

Remarks:

Inspected by Sealer No.

Date 190

FIG. 383.—Watt-hour Meter Investigation Reports.

friendly. In the eyes of the consumer, the meterman or complaint adjuster represents the company, hence his prime duty is to maintain pleasant relations with both present and prospective consumers.

He has also to bear in mind the importance of **attending promptly to any complaints** the consumers may have to make; in short, he

must make it evident to everyone that his company is ready to do all in its power for the convenience of consumers.

Hence the necessity for giving careful attention to such consumers as have already been secured. The company's efforts to obtain new consumers will not be of much avail if the present consumers do not feel that they are receiving just and courteous treatment and good service.

Inquiry tests often take on the same aspect as complaints, although originating with the company, and are handled by a similar routine, as suggested above.

CHAPTER XIV

SERVICE WATT-HOUR METER INSTALLATION DEVICES

CHAPTER XIV

Service Watt-hour Meter Installation Devices

Consumer's service watt-hour meter location, installation methods and the **devices used to facilitate testing** are questions of prime importance to both the consumer and the company supplying the service, and the point at which a watt-hour meter is to be placed should be carefully considered when laying out an installation.

The consideration of the first two subjects is taken up in Chapter VI; the last will be considered here.

A number of **protective devices** have been devised, which, when used improve the appearance of the watt-hour meter installation, provide a ready means of testing and protect the watt-hour meter and service wires from tampering.

An **acceptable auxiliary device** for use with an electricity meter may be defined broadly as one which permits of so adjusting the meter that the combination of meter and auxiliary device registers with reliability and commercial accuracy the energy supplied to the receiving circuit. Auxiliary apparatus which does not belong to an acceptable type should never be used as a part of a standard meter installation.

The devices illustrated, together with their enclosure, are made with fire-proof materials, and are so arranged that the metal conduit leading from the service may enter the trim, or enclosure, thus protecting the service conductors from the point of entrance to the building to the load side of the meter.

The meter and device may be assembled and wired in advance and sent to the consumer's premises ready for connection to the service. This is an advantage in that it makes unnecessary any extensive installation work on the premises of a consumer, and it also permits the wiring and assembling to be done in the supply department, at a time convenient to the central station, and by other than expert wiremen.

The development of service protectors has been carried along lines to facilitate and accelerate the testing of meters, and at the same time without in any way interfering with the functions of the device or affecting the continuity of the consumer's service; this latter feature being of particular value where translating devices such as motors, arc lamps,

et cetera, requiring the polarity to remain unchanged, are in the circuit.

Where the devices are used in conjunction with polyphase watt-hour meters, the work of testing may be done by an ordinary routine tester, rather than one having special training, since no intricate connections are necessary and there is no possibility of reversing the phases.

A full line of protective devices are illustrated in their various applications to several types of watt-hour meters in Figs. 384 to 389. The device is designed to protect the watt-hour meter service wiring; the meter's internal mechanism and the service cut-out, and to afford convenient facilities for testing the watt-hour meter without the necessity of disconnecting the meter wiring and without affecting the continuity of the consumer's service. This latter feature is accomplished by means of a testing plug, forms of which are shown in Fig. 390 and contacts embodied in the cut-out block, as shown in the various figures, when the iron meter connection box covers have been removed. In Fig. 391 is shown a diagram of connections and explanatory sketches, indicating the use of this device in connection with consumer's watt-hour meter testing.

The accompanying figures show very clearly several complete installations of protective watt-hour meter connection boxes, watt-hour meter testing blocks with protective boxes for the same, and several forms of scaling straps and seals, in various suggestive combinations. These devices are manufactured by the Metropolitan Engineering Company, of Brooklyn, N. Y.

A type of terminal device illustrated in Fig. 392 consists essentially of a small iron box or fitting, with facilities for terminating the service and watt-hour meter wiring, as described below.

Inside of each box is a porcelain block, upon which are mounted five brass terminals. The feed wires enter the box through conduit, and on the opposite side are five holes large enough to pass No. 10 B. & S. gauge wire which leads to the watt-hour meter. This side of the box is closed by a steel plate and sealed until such time as the lighting company wishes to connect with the circuit.

These boxes are equipped so that the electrical contractor can attach his wires to one end of the terminals, and when the lighting company is ready to connect the current it attaches its wires to the opposite end of the terminals and then connects with the watt-hour meter.

These boxes are also designed so that the cover, as well as the steel plate on the side of the box, can be sealed, and are manufactured by the Appleton Electric Company, of Chicago, Ill.

Fig. 384.—Protective Devices Applied to Various Types of Watt-hour Meters. Closed. Metropolitan Engineering Company.

FIG. 385.—Protective Devices Applied to Watt-hour Meters. Open and Closed. Metropolitan Engineering Company.

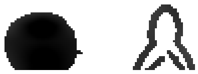


FIG. 386.—Protective Device Applied to Watt-hour Meter. Cover Removed. Metropolitan Engineering Company.

FIG. 387.—Protective Devices Applied to Watt-hour Meters. Open and Closed. Metropolitan Engineering Company.

FIG. 388.—Protective Devices Applied to Different Types of Watt-hour Meters. Metropolitan Engineering Company.

FIG. 389.—Protective Devices with Sealed Service Cut-out. Metropolitan Engineering Company.

The **sealing of watt-hour meters and protective devices** is of the utmost importance. In order to obtain the best results a good appliance should be adopted and the routine of the sealing system carefully maintained.

The basis of any system of sealing should be that none but an authorized representative of the company have access to the seals, or sealing tools, and that the breaking of a seal by other than those whose duty may require it, be not tolerated.

Every watt-hour meter should be sealed when set and a record made on the test, or installation card, specifying the number, or symbol,

FIG. 390.—Forms of Testing Plugs. Metropolitan Engineering Company.

of the seal of the latest employee at the meter, the number or symbol-bearing device being charged to a single employee and restricted to use by him. To maintain the system and definitely fix the responsibility for the condition of the meter, the employee next visiting the meter should be required to note on his test, or inspection, card, the number of the seal he finds, as well as his own, which he attached to the meter. The examination of the seal before removal will indicate if tampering with the meter has been attempted or accomplished. If tampering is suspected, the defective seal should accompany the inspector's report.

The record of the seals removed and attached provides a system useful in checking both the character of inspection and the different employees having access to the meter.

The fundamental qualifications of an acceptable seal are that, when closed or sealed, it be impossible to open it without leaving readily perceptible indication of the fact. It should be so constructed, if of the locking type, as to be positive in action and if of the compression type, the withdrawal of the sealing tool should be prevented until the seal is firmly pressed with the design on the tool

Seals may be divided into two classes; first, those requiring a seal-

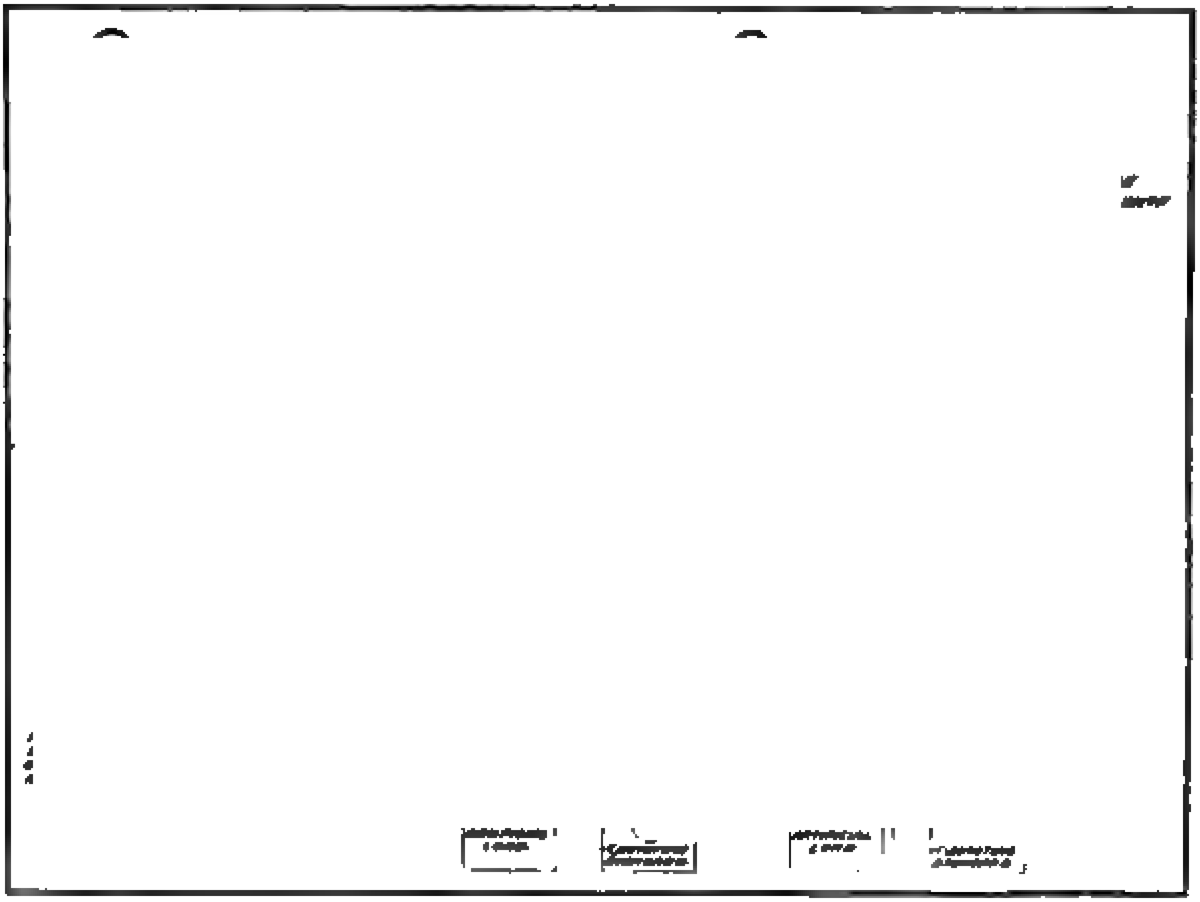


FIG. 391.—Diagram of Connections Indicating the use of Testing Plugs with Devices of the Metropolitan Engineering Company

ing tool to close and impress the private mark of the company, and second, those self-closing, after application in a manner comparable with the closing of a spring lock.

Several devices of the latter type are available, such as the all-porcelain seal with metal shackle and the metal seal and shackle with porcelain breakable button, as illustrated in Fig 393.

In the all-porcelain design, the seal is so constructed that the barbs of the metallic shackle when driven home engage the interior walls of the seal and cannot be withdrawn except by breaking the wire or

the porcelain seal itself. **The metallic type** of seal is essentially the same in principle as the porcelain seal. It is of metal, having a breakable porcelain button through which the shackle is passed. This seal may be used indefinitely by installing new breaking buttons. On the face or back of either type of seal may be placed the name of the company, or such identification marks as may be desired.

Another type, known as the "Security Seal," is illustrated in Fig. 394.

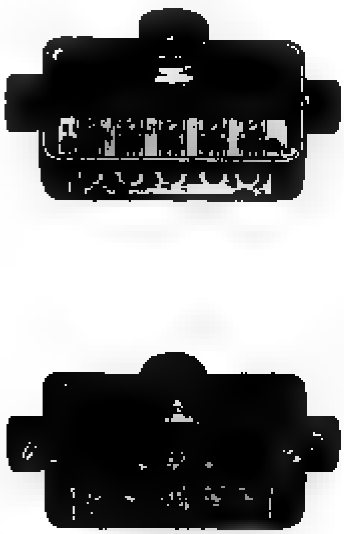
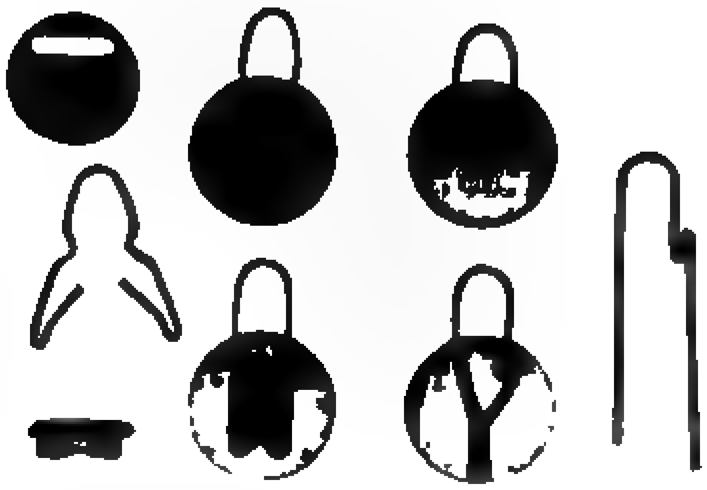


FIG. 392 —Terminal Device for Watt-hour Meters. Appleton Electric Company.

These seals are composed of four units, namely: a pair of straps, which take the place of sealing wire on the cover of the meter, a locking unit, a cap for sealing with wire where straps cannot be used and a renewable plunger.

All parts with the exception of the plunger are permanent and will probably last as long as the meter. The plungers which are now being furnished are made of white metal, by die casting process, and are furnished with the initials of the company using them on

one side of the head, and with the tester's or installer's number on the other side. The plunger is so designed that expensive dies are necessary to manufacture them and they cannot be duplicated by an individual except at prohibitive expense. The plungers can also be



(a) (b) (c) (d)

FIG. 393.—Seals of Porcelain Type. (a) Metallic Seal with Breakable Porcelain Button. (b) Porcelain Seal with Metallic Shackle. (c) Porcelain Seal with Twisted Wire. (d) Sealing Wire. Metropolitan Engineering Company.

made of gutta-percha, glass, aluminum or other material. If porcelain plungers are desired they can be furnished with the initials molded on one side of the head and the other side left blank for the purpose of stamping or marking the sealing date, the man's num-

ber, or any other marking which may be desirable to use. A rubber stamp with changeable figures can be made for each man so that the date and the man's number can be impressed upon the head at the time of sealing. This dating system is now used by one of the largest light and power companies in the country and has a number of advantages.

In locking the seal it is only necessary to snap a renewable plunger into the locking unit. To open the seal the head of the

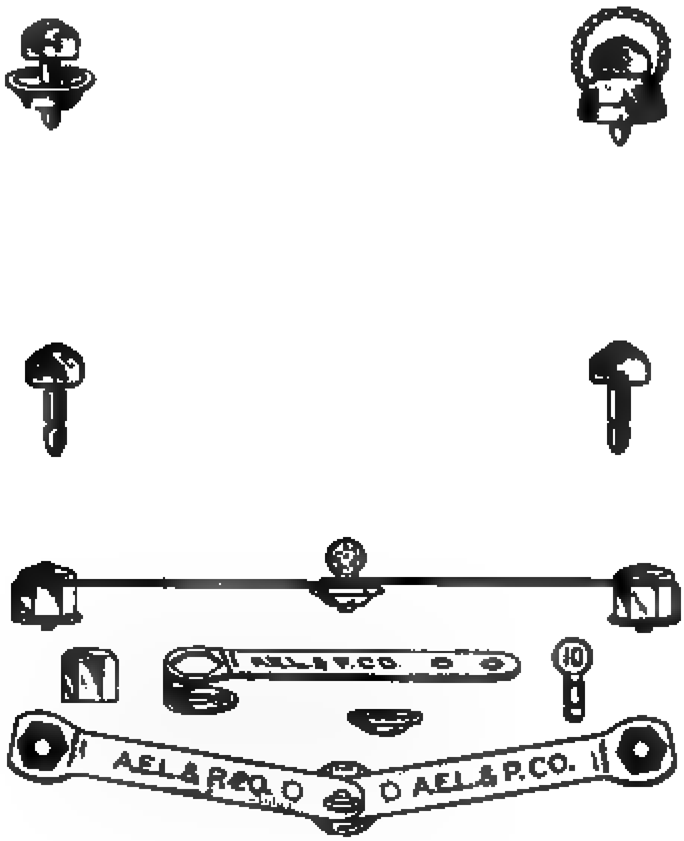


FIG. 394.—Seal with Straps and Removable Plunger. Security Seal Company.

plunger must be severed from the shank, after which the shank can be pushed through and out of the locking unit and a new plunger can then be used to reseal. This seal is so designed as to permit its use either with straps or wires.

The straps have six points of adjustment in their outer ends, which permits making the cover as tight as desired with the arms in correct position for sealing.

The strap method is a neat and convenient method of sealing and saves time. The straps are interchangeable for different makes

types of meters and are furnished with the initials of the company using them stamped on each strap. The straps can also be furnished with initials on one strap and the company's number of the meter on the other.

The seals shown in Figs. 395, 396 and 397 represent the general design of **lead lock and wire hasp seals** of several types; modifications differing only in the shape of the button or the sealing wire not being in-

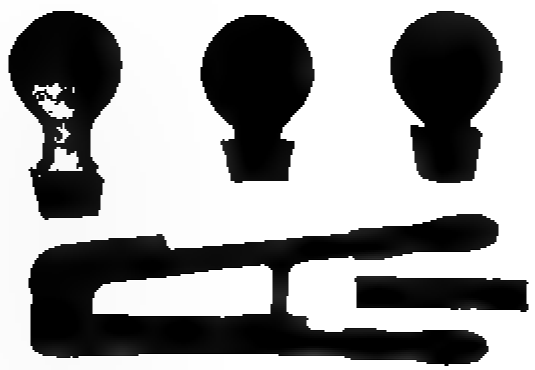


FIG. 395.—Seals of Padlock Lead Type. Keystone.

cluded; in general they represent all of those available desirable and for sealing purposes.

The "lead pipe" seal, shown in Fig. 398, is a seal which may be made up by the central station company, as it consists simply of a piece of sealing wire, which is twisted together in the usual manner, and a piece of small ⅛ inch lead pipe is slipped over the twisted end, flattened out, doubled back, and pressed and stamped with the sealing tool. The meterman simply carries a small coil of sealing wire and a few feet of the lead pipe, from which he constructs the seal, as indicated above and shown in the figure.

The difference between this lead seal and those of the Chicago

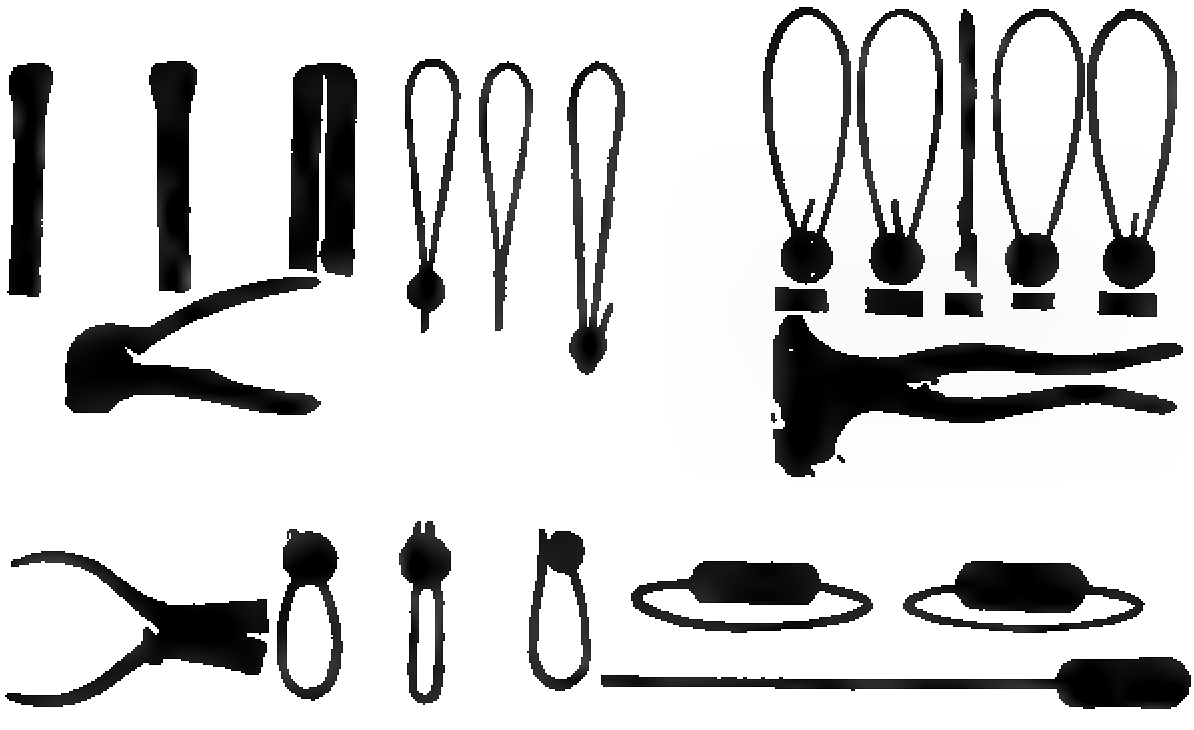


FIG. 396.—Seals of Wire Hasp Lead Types.

car seal type lies in its method of manufacture and possible convenience from this feature and its entire dependence on the sealing tool and the impressed identification mark for its security.

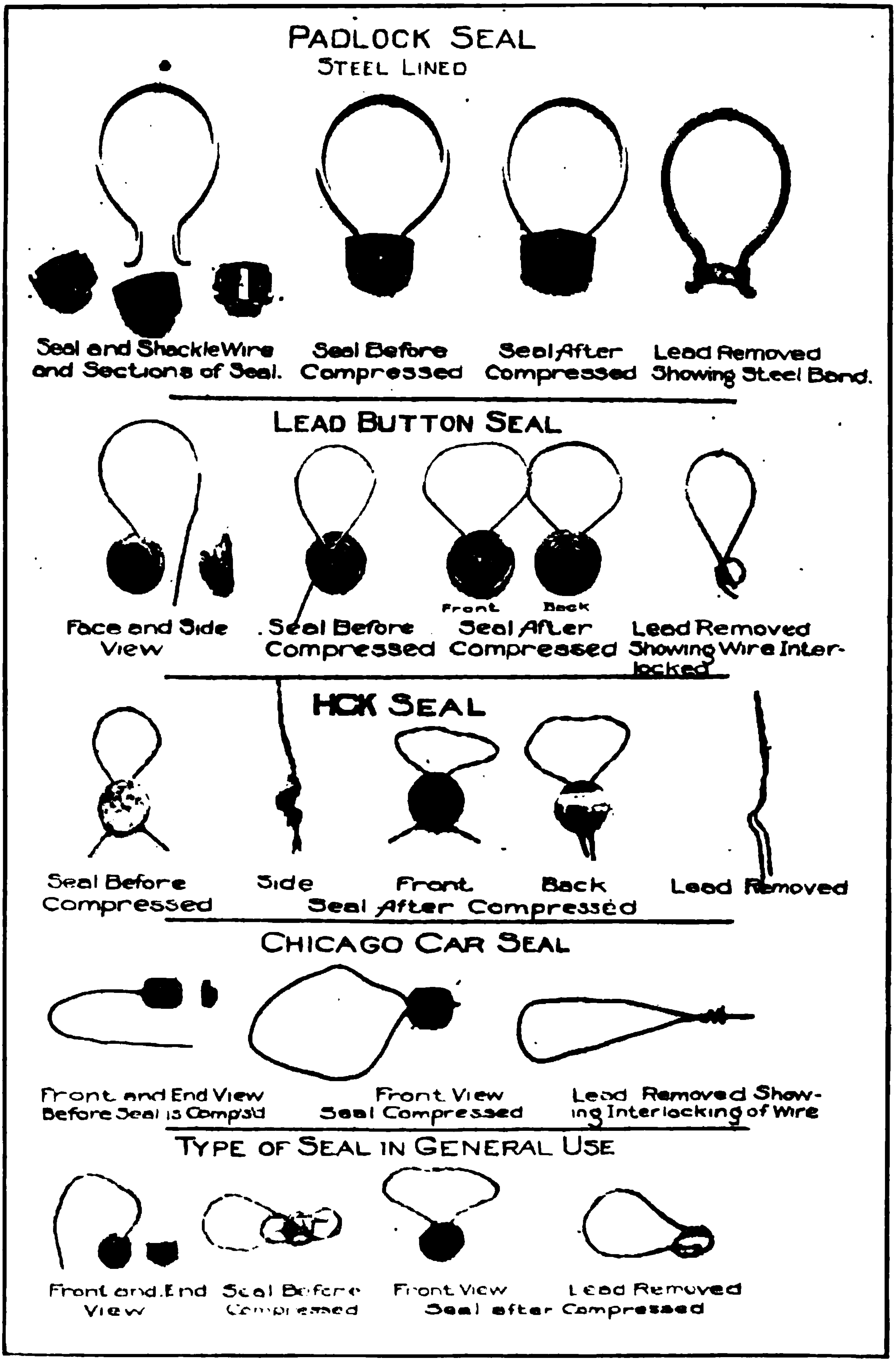


FIG. 207.—Details of Seals, Lead Types.

The selection of a seal should be very carefully considered. Consideration should be given to its reliability as a protective device, and to its qualifications with respect to mechanical strength and ease of application.

It will be noted that some of these meters are sealed by means of straps and some by means of wires. The straps are used in conjunction with the renewable type of seal, exemplified by the

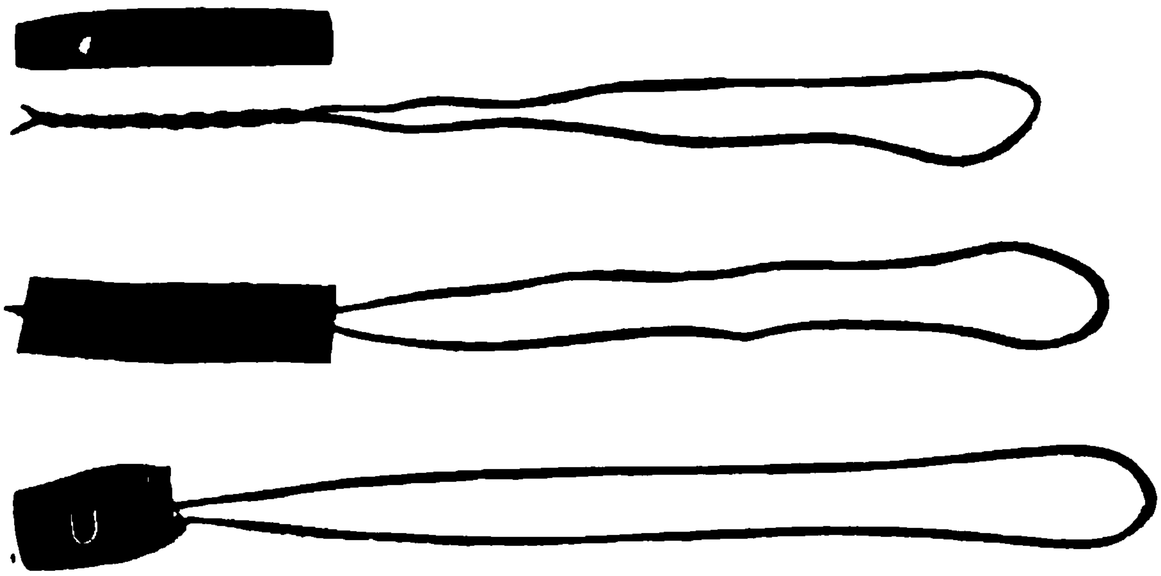


Fig. 398.—Seals of Lead Pipe Type.

Security Seal, and are permanent, being fitted to the particular meter and being used repeatedly in connection with the renewable unit of the particular type of seal utilized. These straps may be of aluminum, which makes it difficult for an unauthorized person to cut the strap and solder it together again; are sometimes perforated with the company's initials, or otherwise stamped or identified; and may be adjustable, to properly fit several sizes and makes of meters, as exemplified by the Security straps in Fig. 394.

CHAPTER XV

WATT-HOUR METER CONSTANTS AND TEST FORMULAS

CHAPTER XV

Watt-hour Meter Constants and Test Formulas

A constant is a quantity used in a formula, the value of which remains the same, regardless of the values of the other quantities used in the formula.

In testing an electricity meter by using indicating instruments and a stop watch, see Chapter VIII, the number of units which have passed through the meter during the period of test is determined by counting the number of revolutions of the moving element, noting the time in seconds required for the moving element to make the counted number of revolutions and using the formula designated by the manufacturer of the meter being tested.

To use this formula it is necessary to multiply the counted number of revolutions by several factors and divide the product by the number of seconds noted.

One of the factors by which the counted number of revolutions is multiplied is a quantity designated by the manufacturer. This quantity is the same for all meters of the same make, type, style and capacity. Therefore, since the value of this quantity remains the same, regardless of the values of the other quantities used in the calculation, it is a constant.

There are several other quantities designated by the manufacturers which are similarly used in calculations pertaining to the registration of meters. Since the values of these quantities do not change for meters of the same make, type, style and capacity,. they are also constants.

The practice of the various manufacturers differs in regard to the information they mark upon meters and no uniformity exists as to the amount, character or location of the information marked thereon.

This lack of uniformity is strikingly noticeable in the manner in which the various manufacturers mark the dials of meters, and in the various terms in which the different constants of a meter are expressed.

The constants of a meter are:

(1) Test Constant (Symbol K_t).

The test constant is usually designated by the letters "K" or "C" in literature pertaining to meter testing, and is frequently termed

"Testing Constant"
"Disk Constant"
"Meter Constant"
"Calibrating Constant"
"Calibration Constant"
"Constant"
"K"
"C"

(2) Watt-Hour Constant (Symbol K_h).
(3) Watt-Second Constant (Symbol K_s).
(4) Register Constant (Symbol K_r).

In the literature distributed by the manufacturers the register constant is frequently termed:

"Dial Constant"
"Multiplier"

These four constants are at times indiscriminately referred to as "Meter Constants."

In the following paragraphs each constant is defined, and the values used for the various makes, types, styles and capacities of meters manufactured by prominent American manufacturers of the present day are tabulated, together with other information necessary to enable one to locate them on the various makes.

In order to insure a complete understanding of the explanations that follow, the meanings of the various words and phrases used throughout the explanations are given by the following definitions.

The following symbols have been standardized and will be used throughout this article.

Gear ratio	R_g
Register constant	K_r
Register ratio	R_r
Revolutions	R
Seconds	S
Test constant	K_t
Watt-hour constant	K_h
Watt-second constant	K_s

The following definitions have been standardized:

The dials are the graduated circles over which the dial hands move.

The dial hands are those parts of the register that move over the dials and point to the numbers on the divisions of the dials.

The dial face is that part of the register on which the dials are placed.

The test dial is an extra, graduated circle, placed upon the dial face or other part of the register, of some meters. The test dial is used only when testing and should never be used when reading the meter.

The first dial is the graduated circle over which the most rapidly moving dial hand passes; the test dial, if any exists, not being considered.

The dial train consists of all the wheels and pinions used as gearing to interconnect the dial hands.

The register is that part which consists of the wheel meshing with the worm or pinion on the moving element shaft; all wheels, pinions, worms, etc., between the worm or pinion on the moving element shaft and the first dial hand; all wheels, pinions, etc., connecting the dial hands in train of gears, and all dial hands, dials, dial face and supporting frame.

The register ratio (Symbol R_r) is the number of revolutions required to be made by the wheel meshing with the worm or pinion on the moving element shaft to cause the first dial hand to make one revolution.

The gear ratio (Symbol R_g) is the number of revolutions required to be made by the moving element to cause the first dial hand to make one revolution.

A standard register is one in which each of the dials is divided into ten equal parts, the parts being numbered from 0 to 9, both inclusive; the gearing between the dial hands being such that the relative movements of the adjacent dial hands are in opposite directions, and in a 10 to 1 ratio; the constant necessary to use in conjunction with the register reading being 1, 10, 100 or 1,000 expressed in the desired unit.

The register reading is the numerical value indicated by the dial hands on the dials the divisions of the dials considered as having the numerical values as marked on the dial face, the test dial, if any exists, not being considered.

The register constant (Symbol K_r) is the factor used in conjunction with the register reading in order to ascertain the total amount of electrical energy, in the desired unit, that has passed through the meter.

The registration is the numerical quantity expressed in the desired unit corresponding in value to the energy that has passed through the meter. It is equal to the product of the register reading and the register constant. The registration during a given interval of time is equal to the

product of the register constant and the difference between the register readings at the beginning and the end of the interval.

The test constant (Symbol K_t) is the constant designated by the manufacturer to be used in the application of the formula furnished by him to check the accuracy of his meter.

The watt-hour constant (Symbol K_h) is the value of the electrical energy expressed in watt-hours required to be passed through the meter in order to cause the moving element to make one revolution.

The watt-second constant (Symbol K_s) is the value of the electrical energy expressed in watt-seconds required to be passed through the meter in order to cause the moving element to make one revolution.

Register Gearing.—As stated elsewhere, to register properly the current or energy consumed it is necessary to register the number of revolutions of the moving element. To accomplish this the moving element is arranged to drive a registering mechanism or register.

It is desirable to have the dials indicate in commercial units, and as each revolution generally represents but a very small fraction of a unit it is necessary to employ a train of gears to obtain the proper speed at the dials.

The relative speed of a driven to a driving gear depends upon the ratio of the number of teeth.

In Fig. 399 is shown the gear A with 30 teeth driving the gear B having 15 teeth, and the gear C with 30 teeth driving the gear D having 10 teeth, therefore

$$1 \text{ revolution of } A = \frac{30}{15} \text{ or } 2 \text{ revolutions of } B$$

and

$$1 \text{ revolution of } C = \frac{30}{10} \text{ or } 3 \text{ revolutions of } I$$

As B and C are mounted on the same shaft, they will necessarily have the same speed, and one revolution of A will produce 6 revolutions of D.

This relation may be expressed thus:

$$\frac{A \times C}{B \times D} = \text{Revs. of } D \text{ to one of } A \text{ or}$$

$$\frac{30 \times 30}{15 \times 10} = 6 \text{ Revs. of } D \text{ to one of } A$$

Resulting in an increase in speed.

When the gear D drives C and B drives A, the relation may be expressed as follows:

$$\frac{D \times B}{C \times A} = \text{Revs. of } A \text{ to one of } D \text{ or}$$

$$\frac{10 \times 15}{30 \times 30} = \text{One-sixth revolution of } A \text{ to one of } D$$

Resulting in a reduction of speed.

In the dial train of meter registers, a reduction of speed is desirable so that the method of calculation given may be employed to determine the speed of a train of gears having any number of gear wheels. The

FIG. 309.—Simple Gearing.

arrangement of gears shown represents the general method employed in meters to reduce the speed of the register.

A worm and worm wheel are frequently used in connection with gears for speed reduction.

A single worm is simply a screw thread on a shaft and in a train of gears acts similarly to a gear having but one tooth. Usually the worm is arranged so as to engage a worm wheel or gear having a correspondingly large number of teeth. A double worm is sometimes employed, consisting of two screw threads on a shaft, which acts as a gear with two teeth.

In calculations a single worm should be considered as a gear having one tooth and a double worm as a gear having two teeth.

A worm or gear mounted on the shaft of the moving element is generally used to drive the gear train which actuates the dial hands.

Various arrangements of gears and worms are employed to produce practically the same results, several of which are shown in Figs. 400 to 403.

In Fig. 400 *K* represents an idler wheel, which is two gears on a com-

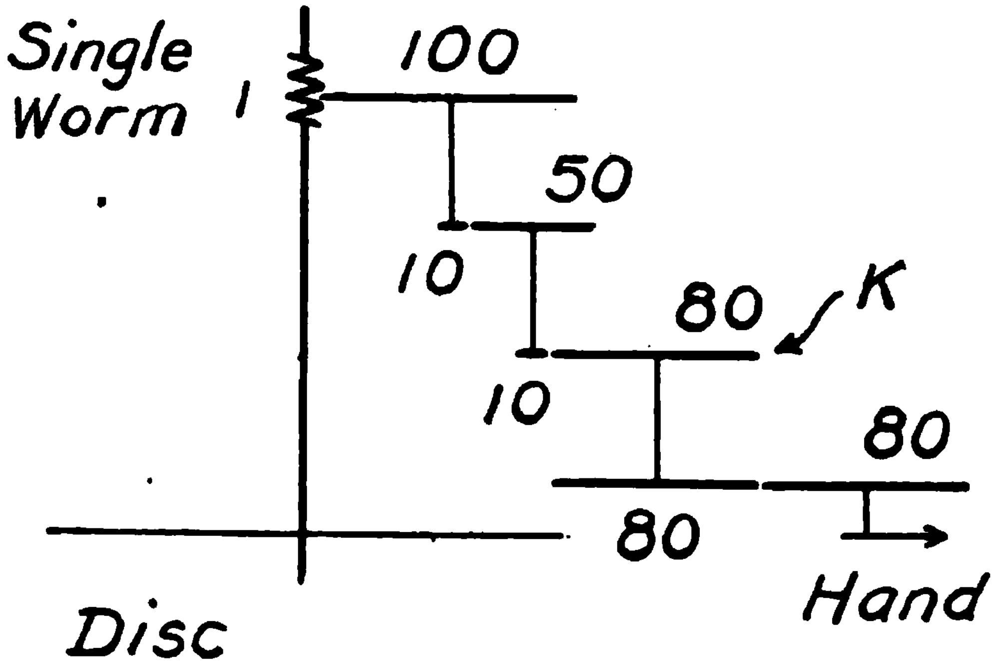


FIG. 400.—Dial Train with Worm on Moving Element Shaft.

mon shaft, each having the same number of teeth. The idler does not change the speed, but is used to reverse the direction of the dial hand.

In Fig. 401 a gear on the shaft connects the moving element to the train, and a double worm is used, as indicated by *L*.

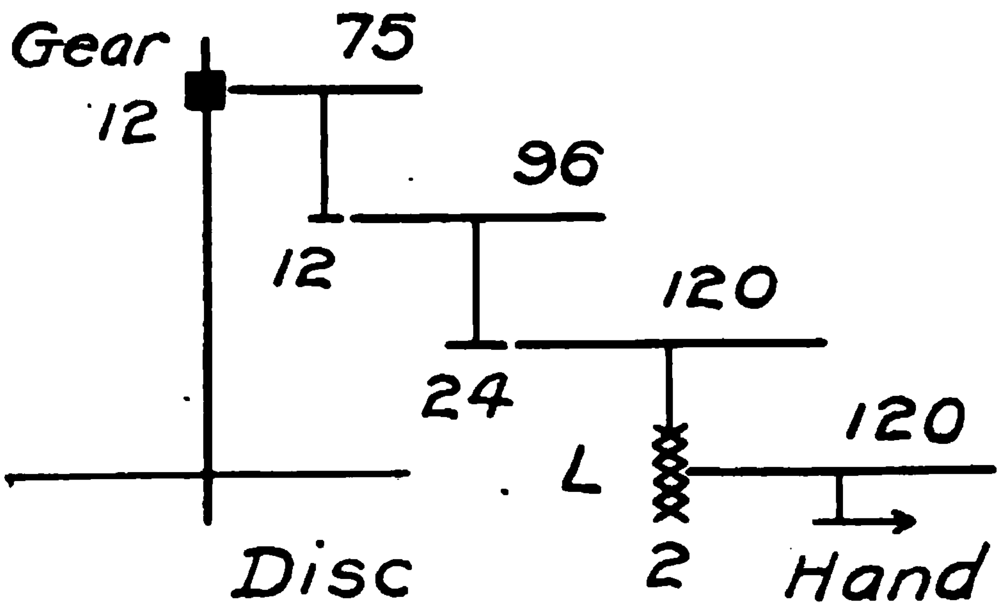


FIG. 401.—Dial Train with Pinion on Moving Element Shaft.

In Fig. 402 two single worms are used, to reduce the number of gears necessary to obtain the desired speed.

It is sometimes desirable to ascertain the number of revolutions of the ·ving element required to make a complete revolution of the first dial

hand. When the number of teeth in each gear wheel has been determined, a convenient method of arranging the gears to facilitate calculation is shown in Fig. 403, and the example shows the calculation necessary.

Example:

$$\frac{100 \times 48 \times 36 \times 40 \times 120}{1 \times 12 \times 12 \times 12 \times 12} = 40{,}000 \text{ revolutions of the moving ele-}$$

ment necessary to produce one complete revolution of the first dial hand.

Arrange the figures representing the number of teeth in the gear wheels according to their relative position in the gear train, as shown in the diagram, and draw the diagonal line *AA*. It will be noted that

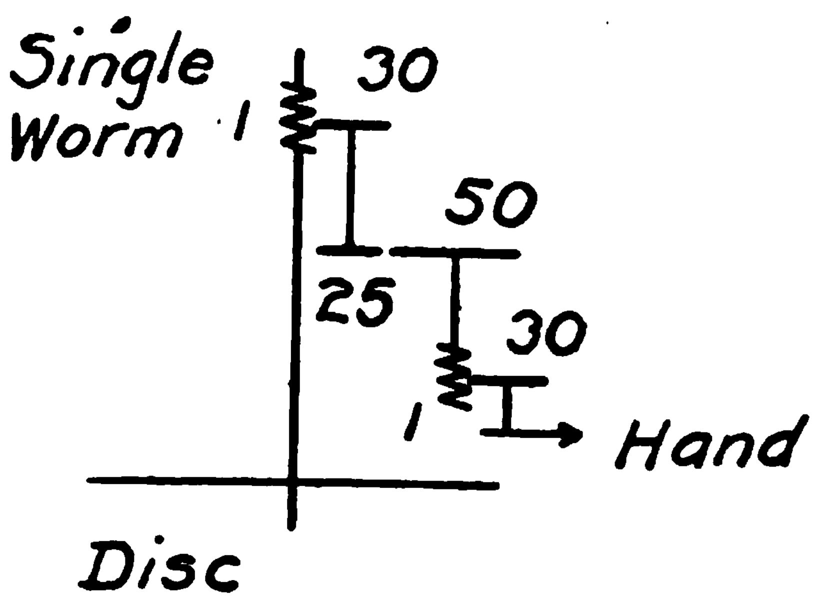


FIG. 402.—Dial Train with Two Worms.

the number of teeth in the driven gears are above the diagonal line and the number of teeth in the driving gears are all below the line. When the product of the numbers above the line is divided by the product of the numbers below the line, the result will be the gear ratio or the number of revolutions of the moving element required to make a complete revolution of the first dial hand.

When the total number of watt-seconds registered by one revolution of the first dial hand is divided by the number of revolutions of the moving element necessary to produce one complete revolution of the first dial hand, the result will represent the value on the dial of one revolution of the moving element in watt-seconds, which is the constant used in the general formula

$$\frac{\text{Watt-seconds (per revolution)} \times \text{revolutions}}{\text{Seconds}} = \text{meter watts}$$

By dividing the watt-seconds per revolution of the moving element by 3,600, the value of one revolution in watt-hours may be obtained, which is the constant used in the formula

$$\frac{3{,}600 \times \text{revolutions} \times \text{constant}}{\text{Seconds}} = \text{meter watts}$$

(1) **The test constant,** standard symbol K_t, is the constant designated by the manufacturer to be used in the application of the formula furnished by him to check the accuracy of his meter.

The test constant designated to be used by the different manufacturers is expressed in various units. Some manufacturers express it in watt-

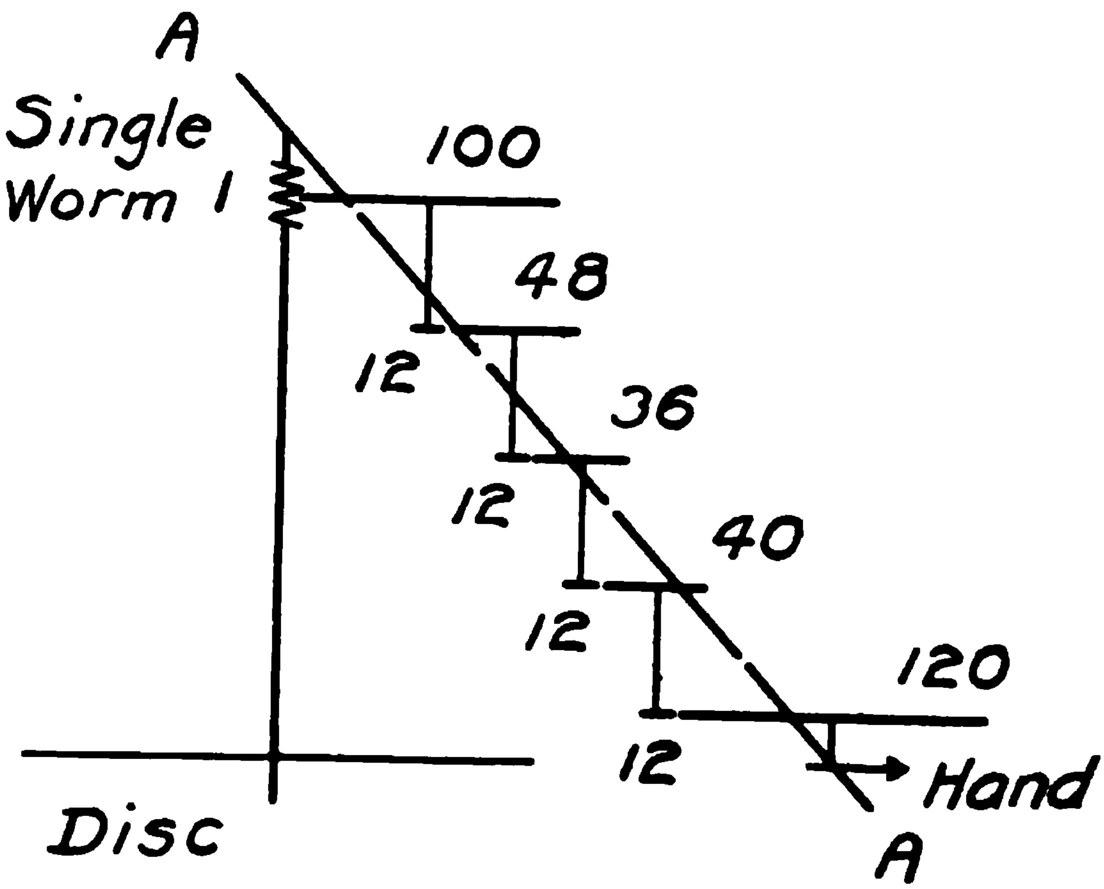


FIG. 403.—Method of Obtaining Gear Ratio.

hours or a multiple thereof, others in watt-seconds. It can in all cases, however, be reduced to watt-hours, or watt-seconds.

In a following section formulas are given by which the watt-hour constant or the watt-second constant of a meter can be found if the test constant is known.

The following table shows on what part of the various makes of meters the test constant can be found.

NOTE: The value of the test constant is in most cases marked on the meter and should be obtained from the meter when possible.

Make of Meter	Location of Test Constant on Meter	Significance of Test Constant
General Electric	On the front of the dial face or terminal board on the old type of meters. On the moving element on the modern types.	Watt-hours per revolution of moving element.
Westinghouse	Not marked on meter. On the interior of the terminal chamber cover is marked the number of revolutions of the moving element per a stated number of kilowatt-hours; from these given values the test constant can be found by multiplying the given number of kilowatt-hours by 3,600,000 and dividing by the given number of revolutions.	Watt-seconds per revolution of moving element. (All types except CW-6.) For type CW-6—watt-hours per revolution of moving element.
Fort Wayne	On the moving element.	For Type K meters, 36 times watt-hours per revolution of moving element. For Types K1, K2, K3 and K4 meters, watt-hours per revolution of moving element.
Sangamo	Type H (alternating current)—On top of register. Type F (alternating current)—On the moving element. Type D (continuous current)—On the moving element.	Watt-seconds per revolution of moving element.

Make of Meter	Location of Test Constant on Meter	Significance of Test Constant
Duncan	Models A and M—On the moving element. Model E—On the bracket supporting the compensating switch.	Watt-hours per revolution of moving element.
Columbia	Types C, C-1, C-2, C-3 and C-4, on the name plate. Type D—On a label inside the meter cover or on the name plate.	Watt-seconds per revolution of moving element.

Immediately following are given **the formulas used in testing various makes of watt-hour meters,** when **indicating instruments** and a stop watch are used, also tables containing the test constants necessary to be used in the formulas.

The standard formula for testing all types and capacities of General Electric watt-hour meters when using indicating instruments and a stop watch is

$$\text{Watts} = \frac{3{,}600 \times K_t \times R}{S}$$

in which

R = Number of complete revolutions of the moving element.
S = Number of seconds required for R revolutions.
K_t = Test constant.
3,600 = Number of seconds in one hour.

In the literature pertaining to watt-hour meter testing distributed by the General Electric Company the testing formula appears as follows:

$$\text{Watts} = \frac{3{,}600 \times K \times R}{S}$$

in which

R = Number of revolutions.
S = Number of seconds required to make this number of revolutions.
K = The constant.
3,600 = Number of seconds in an hour.

TABLE OF TEST CONSTANTS FOR THOMSON WATT-HOUR METERS

Forms J, JN, J-1, FN, DN, D-1, J-2 and D-2

Style	Volts	Amperes	J, JN, J-1, FN, DN, D-1	J-2 D-2	J-2 D-2
			Test Constant (watt-hours)	Test Constant (watt-hours)	*Ratio of Gears
2-Wire	50-55	5	1/8	0.1	0.1
	"	10	1/2	0.2	0.2
	"	15	1/2	0.3	0.3
	"	25	1/2	0.5	0.5
	"	50	1	1.0	0.1
	"	75	2	1.5	1.5
	"	100	2	2.0	0.2
	"	150	3	3.0	0.3
	"	200	4	4.0	0.4
	"	300	6	6.0	0.6
	"	450	10	10.0	1.0
	"	600	12	12.5	1.25
	"	1200	24	25.0	0.25
	100-110	3	1/5	0.125	0.125
	"	5	1/2	0.2	0.2
	"	10	1/2 or 1	0.4	0.4
	"	15	1	0.6	0.6
	"	25	1	1.0	1.0
	"	50	2	2.0	0.2
	"	75	3	3.0	0.3
	"	100	4	4.0	0.4
	"	150	6	6.0	0.6
	"	200	8	7.5	0.75
	"	300	12	12.5	1.25
	"	450	20	20.0	0.2
	"	600	24	25.0	0.25
	110	1200	48 or 50	50.0	0.5
	200-220	3	1/4	0.25	0.25
	"	5	1/2	0.4	0.4
	"	10	1	0.75	0.75
	"	15	2	1.25	1.25
	"	25	2	2.0	0.2
	"	50	4	4.0	0.4
	"	75	6	6.0	0.6
	"	100	8	7.5	0.75
	"	150	12	12.5	1.25

* Note: Ratio of Gears = Number of divisions passed over by the first dial hand per revolution of the worm wheel, or, the fraction of a revolution of the first dial hand per ten revolutions of the worm wheel. This is not the gear ratio defined above.

TABLE OF TEST CONSTANTS FOR THOMSON WATT-HOUR METERS—(*Continued*)

Style	Volts	Amperes	J, JN, J-1, FN, DN, D-1 Test Constant (watt-hours)	J-2 D-2 Test Constant (watt-hours)	J-2 D-2 *Ratio of Gears
2-Wire	200-220	200	16	15.0	1.5
	"	300	24	25.0	0.25
	"	450	36 or 40	40.0	0.4
	"	600	48 or 50	50.0	0.5
	220	1200	96 or 100	100.0	1.0
	500-550	3	1	0.6	0.6
	"	5	1	1.0	1.0
	"	10	2	2.0	0.2
	"	15	5	3.0	0.3
	"	25	5	5.0	0.5
	"	50	10	10.0	1.0
	"	75	15	15.0	1.5
	"	100	20	20.0	0.2
	"	150	30	30.0	0.3
	"	200	40	40.0	0.4
	"	300	60	60.0	0.6
	"	450	100	100.0	1.0
	"	600	120	125.0	1.25
	550	1200	240	250.0	0.25
	1000-1100	10	3	4.0	0.4
	"	15	5	6.0	0.6
	"	25	10	10.0	1.0
	"	50	20	20.0	0.2
	"	75	30	30.0	0.3
	"	100	40	40.0	0.4
	"	150	60	60.0	0.6
	"	200	80	75.0	0.75
	2000-2200	10	6	7.5	0.75
	"	15	10	12.5	1.25
	"	25	20	20.0	0.2
	"	50	40	40.0	0.4
	"	75	60	60.0	0.6

* Note: Ratio of Gears = Number of divisions passed over by the first dial hand per revolution of the worm wheel, or, the fraction of a revolution of the first dial hand per ten revolutions of the worm wheel. This is not the gear ratio defined above.

TABLE OF TEST CONSTANTS FOR THOMSON WATT-HOUR METERS—(*Continued*)

Style	Volts	Amperes	J, JN, J-1, FN, DN, D-1	J-2 D-2	J-2 D-2
			Test Constant (watt-hours)	Test Constant (watt-hours)	* Ratio of Gears
2-Wire	2000-2200	100	80	75.0	0.75
	"	150	120	125.0	1.25
	"	200	160	150.0	1.5
	"	300	240	250.0	0.25
	"	450	300	400.0	0.4
	"	600	480	500.0	0.5
3-Wire	200-220	3½	¼	0.25	0.25
	"	7½	1	0.6	0.6
	"	15	2	1.25	1.25
	"	25	2	2.0	0.2
	"	50	4	4.0	0.4
	"	75	6	6.0	0.6
	"	100	8	7.5	0.75
	"	150	12	12.5	1.25
	"	200	16	15.0	1.5
	"	300	24	25.0	0.25

* NOTE: Ratio of Gears = Number of divisions passed over by the first dial hand per revolution of the worm wheel, or, the fraction of a revolution of the first dial hand per ten revolutions of the worm wheel. This is not the gear ratio defined above.

THOMSON TYPES C, C-5, C-6 AND C-9 CONTINUOUS CURRENT WATT-HOUR METERS

100-120 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	.2	.2	1	500	50,000
10	10	.4	.4	1	250	25,000
15	10	.6	.6	1	166⅔	16,666⅔
25	10	1.	1.	1	100	10,000
50	10	2.	2.	1	50	5,000
75	10	3.	3.	1	33⅓	3,333⅓
100	10	4.	4.	1	25	2,500
150	10	6.	6.	1	16⅔	1,666⅔
300	10	12.5	12.5	10	80	8,000
600	10	25.	25.	10	40	4,000

200-240 Volts, 2-Wire

5	10	.4	.4	1	250	25,000
10	10	.75	.75	1	133⅓	13,333⅓
15	10	1.25	1.25	1	80	8,000
25	10	2.	2.	1	50	5,000
50	10	4.	4.	1	25	2,500
75	10	6.	6.	1	16⅔	1,666⅔
100	10	7.5	7.5	1	13⅓	1,333⅓
150	10	12.5	12.5	10	80	8,000
300	10	25.	25.	10	40	4,000
600	10	50.	50.	10	20	2,000

THOMSON TYPES C, C-5, C-7 AND C-9 CONTINUOUS CURRENT WATT-HOUR METERS

400-440 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	.75	.75	1	133⅓	13,333⅓
10	10	1.5	1.5	1	66⅔	6,666⅔
15	10	2.5	2.5	1	40	4,000
25	10	4.	4.	1	25	2,500
50	10	7.5	7.5	1	13⅓	1,333⅓
75	10	12.5	12.5	10	80	8,000
100	10	15.	15.	10	66⅔	6,666⅔
150	10	25.	25.	10	40	4,000
300	10	50.	50.	10	20	2,000
600	10	100.	100.	10	10	1,000

500-600 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1.	1.	1	100	10,000
10	10	2.	2.	1	50	5,000
15	10	3.	3.	1	33⅓	3,333⅓
25	10	5.	5.	1	20	2,000
50	10	10.	10.	1	10	1,000
75	10	15.	15.	10	66⅔	6,666⅔
100	10	20.	20.	10	50	5,000
150	10	30.	30.	10	33⅓	3,333⅓
300	10	60.	60.	10	16⅔	1,666⅔
600	10	125.	125.	100	80	8,000

THOMSON TYPES C, C-5, C-6 AND C-9 CONTINUOUS CURRENT WATT-HOUR METERS

200-240 Volts, 3-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	.4	.4	1	250	25,000
10	10	.75	.75	1	133⅓	13,333⅓
15	10	1.25	1.25	1	80	8,000
25	10	2.	2.	1	50	5,000
50	10	4.	4.	1	25	2,500
75	10	6.	6.	1	16⅔	1,666⅔
100	10	7.5	7.5	1	13⅓	1,333⅓
150	10	12.5	12.5	10	80	8,000
300	10	25.	25.	10	40	4,000

THOMSON TYPES CQ AND CQ-2 CONTINUOUS CURRENT WATT-HOUR METERS

100-120 Volts, 2-Wire

50	10	2.	2.	1	50	5,000
75	10	3.	3.	1	33⅓	3,333⅓
100	10	4.	4.	1	25	2,500
200	10	7.5	7.5	1	13⅓	1,333⅓
400	10	15	15.	10	66⅔	6,666⅔

THOMSON TYPES CQ AND CQ-2 CONTINUOUS CURRENT WATT-HOUR METERS (*Continued*)

200-240 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
50	10	4.	4.	1	25	2,500
75	10	6.	6.	1	16⅔	1,666⅔
100	10	7.5	7.5	1	13⅓	1,333⅓
200	10	15.	15.	10	66⅔	6,666⅔
400	10	30.	30.	10	33⅓	3,333⅓

500-600 Volts, 2-Wire

50	10	10.	10.	1	10	1,000
75	10	15.	15.	10	66⅔	6,666⅔
100	10	20.	20.	10	50	5,000
200	10	40.	40.	10	25	2,500

200-240 Volts, 3-Wire

50	10	4.	4.	1	25	2,500
75	10	6.	6.	1	16⅔	1,666⅔
100	10	7.5	7.5	1	13⅓	1,333⅓
200	10	15.	15.	10	66⅔	6,666⅔

THOMSON TYPES CP, CP-2, CP-3 AND CP-4 PREPAYMENT CONTINUOUS CURRENT WATT-HOUR METERS

100-120 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	.125	.125	1	800	80,000
5	10	.2	.2	1	500	50,000
10	10	.4	.4	1	250	25,000
15	10	.6	.6	1	166⅔	16,666⅔
25	10	1.	1.	1	100	10,000

200-240 Volts, 2-Wire

3	10	.25	.25	1	400	40,000
5	10	.4	.4	1	250	25,000
10	10	.75	.75	1	133⅓	13,333⅓
15	10	1.25	1.25	1	80	8,000
25	10	2.	2.	1	50	5,000

200-240 Volts, 3-Wire

3	10	.25	.25	1	400	40,000
5	10	.4	.4	1	250	25,000
10	10	.75	.75	1	133⅓	13,333⅓
15	10	1.25	1.25	1	80	8,000
25	10	2.	2.	1	50	5,000

TABLE OF TEST CONSTANTS FOR GENERAL ELECTRIC HIGH TORQUE INDUCTION METERS, DIRECT READING REGISTERS, 50–140 CYCLES

100–110 VOLTS			500–550 VOLTS		
Amperes	Test Constant (watt-hours)	*Ratio of Gears	Amperes	Test Constant (watt-hours)	*Ratio of Gears
3	0.2	0.2	3	1.0	1.0
5	0.3	0.3	5	1.5	1.5
10	0.6	0.6	10	3.0	0.3
15	1.0	1.0	15	5.0	0.5
25	1.5	1.5	25	7.5	0.75
50	3.0	0.3	50	15.0	1.5
75	5.0	0.5	75	25.0	0.25
100	6.0	0.6	100	30.0	0.3
150	10.0	1.0	150	50.0	0.5

200–220 VOLTS, 2-WIRE			200–220 VOLTS, 3-WIRE		
Amperes	Test Constant (watt-hours)	*Ratio of Gears	Amperes	Test Constant (watt-hours)	*Ratio of Gears
3	0.4	0.4	3½	0.5	0.5
5	0.6	0.6	7½	1.0	1.0
10	1.25	1.25			
15	2.0	0.2	15	2.0	0.2
25	3.0	0.3	25	3.0	0.3
50	6.0	0.6	50	6.0	0.6
75	10.0	1.0	75	10.0	1.0
100	12.5	1.25	100		
150	20.0	0.2	150		

* Note: Ratio of Gears = Number of divisions passed over by the first dial hand per revolution of the worm wheel, or, the fraction of a revolution of the first dial hand per ten revolutions of the worm wheel. This is not the gear ratio defined above.

THOMSON TYPE I WATT-HOUR METERS

110-120 Volts, 2-Wire, Single-Phase
56 Cycles and Above

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	.2	.2	1	500	50,000
5	10	.3	.3	1	333⅓	33,333⅓
10	10	.6	.6	1	166⅔	16,666⅔
15	10	1.	1.	1	100	10,000
25	10	1.5	1.5	1	66⅔	6,666⅔
50	10	3.	3.	1	33⅓	3,333⅓
75	10	5.	5.	1	20	2,000
100	10	6.	6.	1	16⅔	1,666⅔
150	10	10.	10.	1	10	1,000
200	10	12.5	12.5	10	80	8,000
300	10	20.	20.	10	50	5,000
600	10	40.	40.	10	25	2,500

200-240 Volts, 2-Wire, Single-Phase
56 Cycles and Above

3	10	.4	.4	1	250	25,000
5	10	.6	.6	1	166⅔	16,666⅔
10	10	1.25	1.25	1	80	8,000
15	10	2.	2.	1	50	5,000
25	10	3.	3.	1	33⅓	3,333⅓
50	10	6.	6.	1	16⅔	1,666⅔
75	10	10.	10.	1	10	1,000
100	10	12.5	12.5	10	80	8,000
150	10	20.	20.	10	50	5,000
200	10	25.	25.	10	40	4,000
300	10	40.	40.	10	25	2,500
600	10	75.	75.	10	13⅓	1,333⅓

THOMSON TYPE I WATT-HOUR METERS (*Continued*)

500-600 Volts, 2-Wire, Single-Phase
56 Cycles and Above

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	1.	1.	1	100	10,000
5	10	1.5	1.5	1	66⅔	6,666⅔
10	10	3.	3.	1	33⅓	3,333⅓
15	10	5.	5.	1	20	2,000
25	10	7.5	7.5	1	13⅓	1,333⅓
50	10	15.	15.	10	66⅔	6,666⅔
75	10	25.	25.	10	40	4,000
100	10	30.	30.	10	33⅓	3,333⅓
150	10	50.	50.	10	20	2,000
200	10	60.	60.	10	16⅔	1,666⅔
300	10	100.	100.	10	10	1,000
600	10	200.	200.	100	50	5,000

200-240 Volts, 3-Wire, Single-Phase
56 Cycles and Above

3	10	.4	.4	1	250	25,000
5	10	.6	.6	1	166⅔	16,666⅔
10	10	1.25	1.25	1	80	8,000
15	10	2.	2.	1	50	5,000
25	10	3.	3.	1	33⅓	3,333⅓
50	10	6.	6.	1	16⅔	1,666⅔
75	10	10.	10.	1	10	1,000
100	10	12.5	12.5	10	80	8,000
150	10	20.	20.	10	50	5,000
200	10	25.	25.	10	40	4,000
300	10	40.	40.	10	25	2,500
600	10	75.	75.	10	13⅓	1,333⅓

THOMSON TYPE I-8 WATT-HOUR METERS

100-120 Volts, 2-Wire, Single-Phase
56 Cycles and Above

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	.2	.2	1	500	50,000
5	10	.3	.3	1	333⅓	33,333⅓
10	10	.6	.6	1	166⅔	16,666⅔
15	10	1.	1.	1	100	10,000
25	10	1.5	1.5	1	66⅔	6,666⅔
50	10	3.	3.	1	33⅓	3,333⅓
75	10	5.	5.	1	20	2,000

200-240 Volts, 2-Wire, Single-Phase
56 Cycles and Above

3	10	.4	.4	1	250	25,000
5	10	.6	.6	1	166⅔	16,666⅔
10	10	1.25	1.25	1	80	8,000
15	10	2.	2.	1	50	5,000
25	10	3.	3.	1	33⅓	3,333⅓
50	10	6.	6.	1	16⅔	1,666⅔
75	10	10.	10.	1	10	1,000

500-600 Volts, 2-Wire, Single-Phase
56 Cycles and Above

3	10	1.	1.	1	100	10,000
5	10	1.5	1.5	1	66⅔	6,666⅔
10	10	3.	3.	1	33⅓	3,333⅓
15	10	5.	5.	1	20	2,000
25	10	7.5	7.5	1	13⅓	1,333⅓
50	10	15.	15.	10	66⅔	6,666⅔
75	10	25.	25.	10	40	4,000

THOMSON TYPE I-8 WATT-HOUR METERS (*Continued*)

200-240 Volts, 3-Wire, Single-Phase

56 Cycles and Above

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	.4	.4	1	250	25,000
5	10	.6	.6	1	$166\frac{2}{3}$	$16,666\frac{2}{3}$
10	10	1.25	1.25	1	80	8,000
15	10	2.	2.	1	50	5,000
25	10	3.	3.	1	$33\frac{1}{3}$	$3,333\frac{1}{3}$
50	10	6.	6.	1	$16\frac{2}{3}$	$1,666\frac{2}{3}$
75	10	10.	10.	1	10	1,000

THOMSON TYPE I-10 WATT-HOUR METERS

110-120 Volts, 2-Wire, Single-Phase

40-133 Cycles

5	10	.25	.25	1	400	40,000
10	10	.5	.5	1	200	20,000

200-240 Volts, 2-Wire, Single-Phase

40-133 Cycles

5	10	.5	.5	1	200	20,000
10	10	1.	1.	1	100	10,000

200-240 Volts, 3-Wire, Single-Phase

40-133 Cycles

5	10	.5	.5	1	200	20,000
10	10	1.	1.	1	100	10,000

TABLE OF TEST CONSTANTS FOR GENERAL ELECTRIC POLYPHASE METERS, ROUND AND RECTANGULAR PATTERN

		NON-DIRECT READING REGISTERS	DIRECT READING REGISTERS	
Volts	Amperes	Test Constant (watt-hours)	Test Constant (watt-hours)	*Ratio of Gears
100–110	3	...	0.6	0.6
"	5	1	1.0	1.0
"	10	2	2.0	0.2
"	15	3	3.0	0.3
"	25	4	5.0	0.5
"	50	8	10.0	1.0
"	75	12	15.0	1.5
"	100	16	20.0	0.2
"	150	24	30.0	0.3
200–220	3	...	1.25	1.25
"	5	2	2.0	0.2
"	10	4	4.0	0.4
"	15	6	6.0	0.6
"	25	8	10.0	1.0
"	50	15 or 16	20.0	0.2
"	75	24	30.0	0.3
"	100	30 or 32	40.0	0.4
"	150	48 or 50	60.0	0.6
500–550	3	3	3.0	0.3
"	5	5	5.0	0.5
"	10	10	10.0	1.0
"	15	15	15.0	1.5
"	25	25	25.0	0.25
"	50	50	50.0	0.5
"	75	75	75.0	0.75
"	100	100	100.0	1.0
"	150	150	150.0	1.5
1000–1100	3	6	6.0	0.6
"	10	20	20.0	0.2
"	15	30	30.0	0.3
"	25	50	50.0	0.5
"	50	100	100.0	1.0
"	75	150	150.0	1.5
"	100	200	200.0	0.2
"	150	300	300.0	0.3

* NOTE: Ratio of Gears = Number of divisions passed over by the first dial hand per revolution of the worm wheel, or, the fraction of a revolution of the first dial hand per ten ...tions of the worm wheel. This is not the gear ratio defined above.

TABLE OF TEST CONSTANTS FOR GENERAL ELECTRIC POLYPHASE METERS, ROUND AND RECTANGULAR PATTERN—(*Continued*)

NON-DIRECT READING REGISTERS			DIRECT READING REGISTERS	
Volts	Amperes	Test Constant (watt-hours)	Test Constant (watt-hours)	*Ratio of Gears
2000–2200	3	12.5	12.5	1.25
"	10	40	40.0	0.4
"	15	60	60.0	0.6
"	25	100	100.0	1.0
"	50	200	200.0	0.2
"	75	300	300.0	0.3
"	100	400	400.0	0.4
"	150	600	600.0	0.6

* NOTE: Ratio of Gears = Number of divisions passed over by the first dial hand per revolution of the worm wheel, or, the fraction of a revolution of the first dial hand per ten revolutions of the worm wheel. This is not the gear ratio defined above.

THOMSON TYPE D-3 WATT-HOUR METERS

100–120 Volts, Polyphase

56 Cycles and Above

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	.4	.4	1	250	25,000
5	10	.6	.6	1	166⅔	16,666⅔
10	10	1.25	1.25	1	80	8,000
15	10	2.	2.	1	50	5,000
25	10	3.	3.	1	33⅓	3,333⅓
50	10	6.	6.	1	16⅔	1,666⅔
75	10	7.5	7.5	1	13⅓	1,333⅓
100	10	12.5	12.5	10	80	8,000
150	10	15.	15.	10	66⅔	6,666⅔
200	10	25.	25.	10	40	4,000
300	10	40.	40.	10	25	2,500
400	10	50.	50.	10	20	2,000
600	10	75.	75.	10	13⅓	1,333⅓

THOMSON TYPE D-3 WATT-HOUR METERS (*Continued*)

200–240 Volts, Polyphase
56 Cycles and Above

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	.75	.75	1	133⅓	13,333⅓
5	10	1.25	1.25	1	80	8,000
10	10	2.5	2.5	1	40	4,000
15	10	4.	4.	1	25	2,500
25	10	6.	6.	1	16⅔	1,666⅔
50	10	12.5	12.5	10	80	8,000
75	10	15.	15.	10	66⅔	6,666⅔
100	10	25.	25.	10	40	4,000
150	10	30.	30.	10	33⅓	3,333⅓
200	10	50.	50.	10	20	2,000
300	10	75.	75.	10	13⅓	1,333⅓
400	10	100.	100.	10	10	1,000
600	10	150.	150.	100	66⅔	6,666⅔

400–440 Volts, Polyphase
56 Cycles and Above

3	10	1.5	1.5	1	66⅔	6,666⅔
5	10	2.5	2.5	1	40	4,000
10	10	5.	5.	1	20	2,000
15	10	7.5	7.5	1	13⅓	1,333⅓
25	10	12.5	12.5	10	80	8,000
50	10	25.	25.	10	40	4,000
75	10	30.	30.	10	33⅓	3,333⅓
100	10	50.	50.	10	20	2,000
150	10	60.	60.	10	16⅔	1,666⅔
200	10	100.	100.	10	10	1,000
300	10	150.	150.	100	66⅔	6,666⅔
400	10	200.	200.	100	50	5,000
600	10	300.	300.	100	33⅓	3,333⅓

THOMSON TYPE D-3 WATT-HOUR METERS

(*Continued*)

500–600 Volts, Polyphase

56 Cycles and Above

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	2.	2.	1	50	5,000
5	10	3.	3.	1	$33\frac{1}{3}$	$3,333\frac{1}{3}$
10	10	6.	6.	1	$16\frac{2}{3}$	$1,666\frac{2}{3}$
15	10	10.	10.	1	10	1,000
25	10	15.	15.	10	$66\frac{2}{3}$	$6,666\frac{2}{3}$
50	10	30.	30.	10	$33\frac{1}{3}$	$3,333\frac{1}{3}$
75	10	40.	40.	10	25	2,500
100	10	60.	60.	10	$16\frac{2}{3}$	$1,666\frac{2}{3}$
150	10	75.	75.	10	$13\frac{1}{3}$	$1,333\frac{1}{3}$
200	10	125.	125.	100	80	8,000
300	10	200.	200.	100	50	5,000
400	10	250.	250.	100	40	4,000
600	10	400.	400.	100	25	2,500

THOMSON TYPE D-4 WATT-HOUR METERS

100-120 Volts, Polyphase

56 Cycles and Above

3	10	.4	.4	1	250	25,000
5	10	.6	.6	1	$166\frac{2}{3}$	$16,666\frac{2}{3}$
10	10	1.25	1.25	1	80	8,000
15	10	2.	2.	1	50	5,000
25	10	3.	3.	1	$33\frac{1}{3}$	$3,333\frac{1}{3}$
50	10	6.	6.	1	$16\frac{2}{3}$	$1,666\frac{2}{3}$
75	10	7.5	7.5	1	$13\frac{1}{3}$	$1,333\frac{1}{3}$

THOMSON TYPE D-4 WATT-HOUR METERS (*Continued*)

200–240 Volt, Polyphase
56 Cycles and Above

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	.75	.75	1	133⅓	13,333⅓
5	10	1.25	1.25	1	80	8,000
10	10	2.5	2.5	1	40	4,000
15	10	4.	4.	1	25	2,500
25	10	6.	6.	1	16⅔	1,666⅔
50	10	12.5	12.5	10	80	8,000
75	10	15.	15.	10	66⅔	6,666⅔

400–440 Volts, Polyphase
56 Cycles and Above

3	10	1.5	1.5	1	66⅔	6,666⅔
5	10	2.5	2.5	1	40	4,000
10	10	5.	5.	1	20	2,000
15	10	7.5	7.5	1	13⅓	1,333⅓
25	10	12.5	12.5	10	80	8,000
50	10	25.	25.	10	40	4,000
75	10	30.	30.	10	33⅓	3,333⅓

500–600 Volts, Polyphase
56 Cycles and Above

3	10	2.	2.	1	50	5,000
5	10	3.	3.	1	33⅓	3,333⅓
10	10	6.	6.	1	16⅔	1,666⅔
15	10	10.	10.	1	10	1,000
25	10	15.	15.	10	66⅔	6,666⅔
50	10	30.	30.	10	33⅓	3,333⅓
75	10	40.	40.	10	25	2,500

THOMSON TYPE IP-4 PREPAYMENT WATT-HOUR METERS

100-120 Volts, 2-Wire, Single-Phase
56 Cycles and Above

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	.2	.2	1	500	50,000
5	10	.3	.3	1	$333\frac{1}{3}$	$33,333\frac{1}{3}$
10	10	.6	.6	1	$166\frac{2}{3}$	$16,666\frac{2}{3}$
15	10	1.	1.	1	100	10,000
25	10	1.5	1.5	1	$66\frac{2}{3}$	$6,666\frac{2}{3}$

200-240 Volts, 2-Wire, Single-Phase
56 Cycles and Above

3	10	.4	.4	1	250	25,000
5	10	.6	.6	1	$166\frac{2}{3}$	$16,666\frac{2}{3}$
10	10	1.25	1.25	1	80	8,000
15	10	2.	2.	1	50	5,000
25	10	3.	3.	1	$33\frac{1}{3}$	$3,333\frac{1}{3}$

500-600 Volts, 2-Wire, Single-Phase
56 Cycles and Above

3	10	1.	1.	1	100	10,000
5	10	1.5	1.5	1	$66\frac{2}{3}$	$6,666\frac{2}{3}$
10	10	3.	3.	1	$33\frac{1}{3}$	$3,333\frac{1}{3}$
15	10	5.	5.	1	20	2,000
25	10	7.5	7.5	1	$13\frac{1}{3}$	$1,333\frac{1}{3}$

THOMSON TYPE IP-4 PREPAYMENT WATT-HOUR METERS (*Continued*)

200-240 Volts, 3-Wire, Single-Phase

56 Cycles and Above

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	.4	.4	1	250	25,000
5	10	.6	.6	1	166⅔	16,666⅔
10	10	1.25	1.25	1	80	8,000
15	10	2.	2.	1	50	5,000
25	10	3.	3.	1	33⅓	3,333⅓

The standard formula for testing all types and capacities of Shallenberger and Westinghouse watt-hour meters (except Type CW-6) when using indicating instruments and a stop watch is

$$\text{Watts} = \frac{R \times K_t}{S}$$

For CW-6 Watt-hour meters

$$\text{Watts} = \frac{3{,}600 \times K_t \times R}{S}$$

in which

R = Number of complete revolutions of the moving element.
S = Number of seconds required for R revolutions.
K_t = Test constant.
3,600 = Number of seconds in one hour.

In the literature pertaining to watt-hour meter testing distributed by the Westinghouse Company, the testing formulas appear as follows:

$$\text{Watts} = \frac{R \times K}{T}$$

For CW-6 Watt-hour meters

$$\text{Watts} = \frac{3{,}600 \times K \times R}{T}$$

in which

R = Number of complete revolutions in time T.
T = Time in seconds required for revolutions R.
K = Constant.
= Number of seconds in one hour.

VALUES OF TEST CONSTANT FOR VARIOUS TYPES AND CAPACITIES OF WESTINGHOUSE SINGLE-PHASE WATT-HOUR METERS

V = Voltage marked on the meter (see note below).
A = Amperes marked on the meter.

NOTE: When the voltage marking of 3-wire meters covers both the voltage between the neutral and the outer wires, and the voltage between the outer wires, such as 100–200 volts, V = the voltage between the neutral wire and the outer wires.

TYPE OF METER	TWO-WIRE METERS					THREE-WIRE METERS		
	For Self-contained Meters	For Meters Used With Current Transformers Only, but Tested Without	For Meters Used With Current and Voltage Transformers, but Tested Without	For Meters Used With Transformers of Either or Both Forms and Tested With	Full Rated Load Speed	For Self-contained Meters	For Meters Used With Current Transformers Only, but Tested Without	Full Rated Load Speed
Shallenberger Type. Round Pattern back connected Type. Type A.	V x A x 1.2	V x 6	600	V x A x 1.2	50 rev. per min.	V x A x 2.4	V x 6	50 rev. per min.
Type B. Type C. Type OA.	V x A x 2.4	V x 12	1200	V x A x 2.4	25 rev. per min.	V x A x 4.8	V x 12	25 rev. per min.

VALUES OF TEST CONSTANT FOR VARIOUS TYPES AND CAPACITIES OF WESTINGHOUSE POLYPHASE WATT-HOUR METERS

V = Voltage marked on the meter.
A = Amperes marked on the meter.

TYPE OF METER	For Self-Contained Meters	For Meters Used With Current Transformers Only, but Tested Without	For Meters Used With Current and Voltage Transformers, but Tested Without	For Meters Used With Transformers of Either or Both Forms and Tested With	Full Rated Load Speed
Type A.............	V x A x 2.4	V x 12	1200	V x A x 2.4	50 rev. per min.
Type C.............	V x A x 4.8	V x 24	2400	V x A x 4.8	25 rev. per min.

VALUES OF TEST CONSTANT FOR VARIOUS TYPES AND CAPACITIES OF WESTINGHOUSE CONTINUOUS CURRENT WATT-HOUR METERS

V = Voltage marked on the meter (see note below).

A = Amperes marked on the meter.

NOTE: When the voltage marking of 3-wire meters covers both the voltage between the neutral wire and the outer wires, and the voltage between the outer wires, such as 100–200 volts, V = the voltage between the outer wires.

FOR ALL TYPES AND CAPACITIES $K_t = V \times A \times 2.4$.

WESTINGHOUSE ROUND TYPE WATT-HOUR METERS

100 Volts, 2-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	1	600	1/6	1	600	6,000
10	1	1,200	1/3	1	300	3,000
20	1	2,400	2/3	1	150	1,500
40	10	4,800	1 1/3	1	750	7,500
80	10	9,600	2 2/3	1	375	3,750

200 Volts, 2-Wire, Single-Phase

5	1	1,200	1/3	1	300	3,000
10	1	2,400	2/3	1	150	1,500
20	10	4,800	1 1/3	1	750	7,500
40	10	9,600	2 2/3	1	375	3,750
80	10	19,200	5 1/3	1	187 1/2	1,875

400 Volts, 2-Wire, Single-Phase

5	1	2,400	2/3	1	150	1,500
10	10	4,800	1 1/3	1	750	7,500
20	10	9,600	2 2/3	1	375	3,750
40	10	19,200	5 1/3	1	187 1/2	1,875
80	10	38,400	10 2/3	1	93 3/4	937 1/2

WESTINGHOUSE ROUND TYPE WATT-HOUR METERS

(Continued)

100-200 Volts, 3-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	1	1,200	$\frac{1}{3}$	1	300	3,000
10	1	2,400	$\frac{2}{3}$	1	150	1,500
20	10	4,800	$1\frac{1}{3}$	1	750	7,500
40	10	9,600	$2\frac{2}{3}$	1	375	3,750

200-400 Volts, 3-Wire, Single-Phase

5	1	2,400	$\frac{2}{3}$	1	150	1,500
10	10	4,800	$1\frac{1}{3}$	1	750	7,500
20	10	9,600	$2\frac{2}{3}$	1	375	3,750
40	10	19,200	$5\frac{1}{3}$	1	$187\frac{1}{2}$	1,875

100 Volts, Polyphase

5	1	1,200	$\frac{1}{3}$	1	300	3,000
10	1	2,400	$\frac{2}{3}$	1	150	1,500
20	10	4,800	$1\frac{1}{3}$	1	750	7,500
40	10	9,600	$2\frac{2}{3}$	1	375	3,750
80	10	19,200	$5\frac{1}{3}$	1	$187\frac{1}{2}$	1,875

WESTINGHOUSE ROUND TYPE WATT-HOUR METERS

(Continued)

200 Volts, Polyphase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	1	2,400	$\frac{2}{3}$	1	150	1,500
10	10	4,800	$1\frac{1}{3}$	1	750	7,500
20	10	9,600	$2\frac{2}{3}$	1	375	3,750
40	10	19,200	$5\frac{1}{3}$	1	$187\frac{1}{2}$	1,875
80	10	38,400	$10\frac{2}{3}$	1	$93\frac{3}{4}$	$937\frac{1}{2}$

400 Volts, Polyphase

5	10	4,800	$1\frac{1}{3}$	1	750	7,500
10	10	9,600	$2\frac{2}{3}$	1	375	3,750
20	10	19,200	$5\frac{1}{3}$	1	$187\frac{1}{2}$	1,875
40	10	38,400	$10\frac{2}{3}$	1	$93\frac{3}{4}$	$937\frac{1}{2}$
80	100	76,800	$21\frac{1}{3}$	1	$468\frac{3}{4}$	$4,687\frac{1}{2}$

WESTINGHOUSE TYPE A WATT-HOUR METERS

100 Volts, 2-Wire, Single-Phase

5	1	600	$\frac{1}{6}$	1	600	6,000
10	1	1,200	$\frac{1}{3}$	1	300	3,000
20	1	2,400	$\frac{2}{3}$	1	150	1,500
40	10	4,800	$1\frac{1}{3}$	1	750	7,500
80	10	9,600	$2\frac{2}{3}$	1	375	3,750

WESTINGHOUSE TYPE A WATT-HOUR METERS
(*Continued*)

200 Volts, 2-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	1	1,200	$\frac{1}{3}$	1	300	3,000
10	1	2,400	$\frac{2}{3}$	1	150	1,500
20	10	4,800	$1\frac{1}{3}$	1	750	7,500
40	10	9,600	$2\frac{2}{3}$	1	375	3,750
80	10	19,200	$5\frac{1}{3}$	1	$187\frac{1}{2}$	1,875

400 Volts, 2-Wire, Single-Phase

5	1	2,400	$\frac{2}{3}$	1	150	1,500
10	10	4,800	$1\frac{1}{3}$	1	750	7,500
20	10	9,600	$2\frac{2}{3}$	1	375	3,750
40	10	19,200	$5\frac{1}{3}$	1	$187\frac{1}{2}$	1,875
80	10	38,400	$10\frac{2}{3}$	1	$93\frac{3}{4}$	$937\frac{1}{2}$

100-200 Volts, 3-Wire, Single-Phase

5	1	1,200	$\frac{1}{3}$	1	300	3,000
10	1	2,400	$\frac{2}{3}$	1	150	1,500
20	10	4,800	$1\frac{1}{3}$	1	750	7,500
40	10	9,600	$2\frac{2}{3}$	1	375	3,750

WESTINGHOUSE TYPE A WATT-HOUR METERS
(Continued)

200-400 Volts, 3-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	1	2,400	$\frac{2}{3}$	1	150	1,500
10	10	4,800	$1\frac{1}{3}$	1	750	7,500
20	10	9,600	$2\frac{2}{3}$	1	375	3,750
40	10	19,200	$5\frac{1}{3}$	1	$187\frac{1}{2}$	1,875

100 Volts, Polyphase

5	1	1,200	$\frac{1}{3}$	1	300	3,000
10	1	2,400	$\frac{2}{3}$	1	150	1,500
20	10	4,800	$1\frac{1}{3}$	1	750	7,500
40	10	9,600	$2\frac{2}{3}$	1	375	3,750
80	10	19,200	$5\frac{1}{3}$	1	$187\frac{1}{2}$	1,875

200 Volts, Polyphase

5	1	2,400	$\frac{2}{3}$	1	150	1,500
10	10	4,800	$1\frac{1}{3}$	1	750	7,500
20	10	9,600	$2\frac{2}{3}$	1	375	3,750
40	10	19,200	$5\frac{1}{3}$	1	$187\frac{1}{2}$	1,875
80	10	38,400	$10\frac{2}{3}$	1	$93\frac{3}{4}$	$937\frac{1}{2}$

WESTINGHOUSE TYPE A WATT-HOUR METERS

(Continued)

400 Volts, Polyphase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	4,800	$1\frac{1}{3}$	1	750	7,500
10	10	9,600	$2\frac{2}{3}$	1	375	3,750
20	10	19,200	$5\frac{1}{3}$	1	$187\frac{1}{2}$	1,875
40	10	38,400	$10\frac{2}{3}$	1	$93\frac{3}{4}$	$937\frac{1}{2}$
80	100	76,800	$21\frac{1}{3}$	1	$468\frac{3}{4}$	$4,687\frac{1}{2}$

WESTINGHOUSE TYPE B WATT-HOUR METERS

100 Volts, 2-Wire, Single-Phase
Serial Numbers 418,000 (approx.) and under

5	1	1,200	$\frac{1}{3}$	1	480	3,000
10	1	2,400	$\frac{2}{3}$	1	240	1,500
20	1	4,800	$1\frac{1}{3}$	1	120	750
40	10	9,600	$2\frac{2}{3}$	1	600	3,750
80	10	19,200	$5\frac{1}{3}$	1	300	1,875

100 Volts, 2-Wire, Single-Phase
Serial Numbers above 418,000 approx.

5	10	1,200	$\frac{1}{3}$	1	4,836.9	30,230.7
10	10	2,400	$\frac{2}{3}$	1	2,400	15,000
20	10	4,800	$1\frac{1}{3}$	1	1,200	7,500
40	10	9,600	$2\frac{2}{3}$	1	600	3,750
80	10	19,200	$5\frac{1}{3}$	1	300	1,875

WESTINGHOUSE TYPE B WATT-HOUR METERS
(Continued)

200 Volts, 2-Wire, Single-Phase
Serial Numbers 418,000 (approx.) and under

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	1	2,400	⅔	1	240	1,500
10	1	4,800	1⅓	1	120	750
20	10	9,600	2⅔	1	600	3,750
40	10	19,200	5⅓	1	300	1,875
80	10	38,400	10⅔	1	150	937½

200 Volts, 2-Wire, Single-Phase
Serial Numbers above 418,000 (approx.)

5	10	2,400	⅔	1	2,400	15,000
10	10	4,800	1⅓	1	1,200	7,500
20	10	9,600	2⅔	1	600	3,750
40	10	19,200	5⅓	1	300	1,875
80	10	38,400	10⅔	1	150	937½

400 Volts, 2-Wire, Single-Phase
Serial Numbers 418,000 (approx.) and under

5	1	4,800	1⅓	1	120	750
10	10	9,600	2⅔	1	600	3,750
20	10	19,200	5⅓	1	300	1,875
40	10	38,400	10⅔	1	150	937½
80	10	76,800	21⅓	1	75	468¾

WESTINGHOUSE TYPE B WATT-HOUR METERS
(Continued)

400 Volts, 2-Wire, Single-Phase
Serial Numbers above 418,000 (approx.)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	4,800	1⅓	1	1,200	7,500
10	10	9,600	2⅔	1	600	3,750
20	10	19,200	5⅓	1	300	1,875
40	10	38,400	10⅔	1	150	937½
80	100	76,800	21⅓	1	750	4,687½

100-200 Volts, 3-Wire, Single-Phase
Serial Numbers 418,000 (approx.) and under

5	1	2,400	⅔	1	240	1,500
10	1	4,800	1⅓	1	120	750
20	10	9,600	2⅔	1	600	3,750
40	10	19,200	5⅓	1	300	1,875

100-200 Volts, 3-Wire; Single-Phase
Serial Numbers above 418,000 (approx.)

5	10	2,400	⅔	1	2,400	15,000
10	10	4,800	1⅓	1	1,200	7,500
20	10	9,600	2⅔	1	600	3,750
40	10	19,200	5⅓	1	300	1,875

200-400 Volts, 3-Wire, Single-Phase
Serial Numbers 418,000 (approx.) and under

5	1	4,800	1⅓	1	120	750
10	10	9,600	2⅔	1	600	3,750
20	10	19,200	5⅓	1	300	1,875
40	10	38,400	10⅔	1	150	937½

WESTINGHOUSE TYPE B WATT-HOUR METERS

(*Continued*)

200-400 Volts, 3-Wire, Single-Phase

Serial Numbers above 418,000 (approx.)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	4,800	$1\frac{1}{3}$	1	1,200	7,500
10	10	9,600	$2\frac{2}{3}$	1	600	3,750
20	10	19,200	$5\frac{1}{3}$	1	300	1,875
40	10	38,400	$10\frac{2}{3}$	1	150	$937\frac{1}{2}$

WESTINGHOUSE TYPE B PREPAYMENT WATT-HOUR METERS

100 Volts, 2-Wire, Single-Phase

5	10	1,200	$\frac{1}{3}$	1	4,800	30,000
10	10	2,400	$\frac{2}{3}$	1	2,400	15,000
15	10	3,600	1	1	1,600	10,000
20	10	4,800	$1\frac{1}{3}$	1	1,200	7,500

200 Volts, 2-Wire, Single-Phase

5	10	2,400	$\frac{2}{3}$	1	2,400	15,000
10	10	4,800	$1\frac{1}{3}$	1	1,200	7,500
15	10	7,200	2	1	800	5,000
20	10	9,600	$2\frac{2}{3}$	1	600	3,750

WESTINGHOUSE TYPE B PREPAYMENT WATT-HOUR METERS (*Continued*)

100-200 Volts, 3-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	2,400	$\frac{2}{3}$	1	2,400	15,000
10	10	4,800	$1\frac{1}{3}$	1	1,200	7,500
15	10	7,200	2	1	800	5,000
20	10	9,600	$2\frac{2}{3}$	1	600	3,750

WESTINGHOUSE TYPE C WATT-HOUR METERS

100 Volts, 2-Wire, Single-Phase

5	10	1,200	$\frac{1}{3}$	1	4,800	30,000
10	10	2,400	$\frac{2}{3}$	1	2,400	15,000
15	10	3,600	1	1	1,600	10,000
20	10	4,800	$1\frac{1}{3}$	1	1,200	7,500
30	10	7,200	2	1	800	5,000
40	10	9,600	$2\frac{2}{3}$	1	600	3,750
60	10	14,400	4	1	400	2,500
80	10	19,200	$5\frac{1}{3}$	1	300	1,875
100	10	24,000	$6\frac{2}{3}$	1	240	1,500
120	10	28,800	8	1	200	1,250
150	10	36,000	10	1	160	1,000
200	10	48,000	$13\frac{1}{3}$	1	120	750
300	100	72,000	20	1	800	5,000
*5	10	1,200	$\frac{1}{3}$	1	4,836.9	30,230.7
*5	10	1,200	$\frac{1}{3}$	1	4,796.6	29,978.8

* For Type C meters previous to meter Sub E, serial No. 158,000

WESTINGHOUSE TYPE C WATT-HOUR METERS

(*Continued*)

200 Volts, 2-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	2,400	⅔	1	2,400	15,000
10	10	4,800	1⅓	1	1,200	7,500
15	10	7,200	2	1	800	5,000
20	10	9,600	2⅔	1	600	3,750
30	10	14,400	4	1	400	2,500
40	10	19,200	5⅓	1	300	1,875
60	10	28,800	8	1	200	1,250
80	10	38,400	10⅔	1	150	937½
100	10	48,000	13⅓	1	120	750
120	100	57,600	16	1	1,000	6,250
150	100	72,000	20	1	800	5,000
200	100	96,000	26⅔	1	600	3,750
300	100	144,000	40	1	400	2,500

400 Volts, 2-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	4,800	1⅓	1	1,200	7,500
10	10	9,600	2⅔	1	600	3,750
15	10	14,400	4	1	400	2,500
20	10	19,200	5⅓	1	300	1,875
30	10	28,800	8	1	200	1,250
40	10	38,400	10⅔	1	150	937½
60	100	57,600	16	1	1,000	6,250
80	100	76,800	21⅓	1	750	4,687½
100	100	96,000	26⅔	1	600	3,750
120	100	115,200	32	1	500	3,125
150	100	144,000	40	1	400	2,500
200	100	192,000	53⅓	1	300	1,875
300	100	288,000	80	1	200	1,250

WESTINGHOUSE TYPE C WATT-HOUR METERS

(Continued)

500 Volts, 2-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	6,000	1⅔	1	960	6,000
10	10	12,000	3⅓	1	480	3,000
15	10	18,000	5	1	320	2,000
20	10	24,000	6⅔	1	240	1,500
30	10	36,000	10	1	160	1,000
40	10	48,000	13⅓	1	120	750
60	100	72,000	20	1	800	5,000
80	100	96,000	26⅔	1	600	3,750
100	100	120,000	33⅓	1	480	3,000
120	100	144,000	40	1	400	2,500
150	100	180,000	50	1	320	2,000
200	100	240,000	66⅔	1	240	1,500
300	100	360,000	100	1	160	1,000

100-200 Volts, 3-Wire, Single-Phase

5	10	2,400	⅔	1	2,400	15,000
10	10	4,800	1⅓	1	1,200	7,500
15	10	7,200	2	1	800	5,000
20	10	9,600	2⅔	1	600	3,750
30	10	14,400	4	1	400	2,500
40	10	19,200	5⅓	1	300	1,875
60	10	28,800	8	1	200	1,250
80	10	38,400	10⅔	1	150	937½
100	10	48,000	13⅓	1	120	750
120	100	57,600	16	1	1,000	6,250
150	100	72,000	20	1	800	5,000

WESTINGHOUSE TYPE C WATT-HOUR METERS
(*Continued*)

200-400 Volts, 3-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	4,800	1⅓	1	1,200	7,500
10	10	9,600	2⅔	1	600	3,750
15	10	14,400	4	1	400	2,500
20	10	19,200	5⅓	1	300	1,875
30	10	28,800	8	1	200	1,250
40	10	38,400	10⅔	1	150	937½
60	100	57,600	16	1	1,000	6,250
80	100	76,800	21⅓	1	750	4,687½
100	100	96,000	26⅔	1	600	3,750
120	100	115,200	32	1	500	3,125
150	100	144,000	40	1	400	2,500

100 Volts, Polyphase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	2,400	⅔	1	3,000	15,000
10	10	4,800	1⅓	1	1,500	7,500
15	10	7,200	2	1	1,000	5,000
20	10	9,600	2⅔	1	750	3,750
30	10	14,400	4	1	500	2,500
40	10	19,200	5⅓	1	375	1,875
60	10	28,800	8	1	250	1,250
80	10	38,400	10⅔	1	187½	937½
100	10	48,000	13⅓	1	150	750
120	100	57,600	16	1	1,250	6,250
150	100	72,000	20	1	1,000	5,000
200	100	96,000	26⅔	1	750	3,750
300	100	144,000	40	1	500	2,500

WESTINGHOUSE TYPE C WATT-HOUR METERS

(*Continued*)

200 Volts, Polyphase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	4,800	$1\frac{1}{3}$	1	1,500	7,500
10	10	9,600	$2\frac{2}{3}$	1	750	3,750
15	10	14,400	4	1	500	2,500
20	10	19,200	$5\frac{1}{3}$	1	375	1,875
30	10	28,800	8	1	250	1,250
40	10	38,400	$10\frac{2}{3}$	1	$187\frac{1}{2}$	$937\frac{1}{2}$
60	100	57,600	16	1	1,250	6,250
80	100	76,800	$21\frac{1}{3}$	1	$937\frac{1}{2}$	$4,687\frac{1}{2}$
100	100	96,000	$26\frac{2}{3}$	1	750	3,750
120	100	115,200	32	1	625	3,125
150	100	144,000	40	1	500	2,500
200	100	192,000	$53\frac{1}{3}$	1	375	1,875
300	100	288,000	80	1	250	1,250

400 Volts, Polyphase

5	10	9,600	$2\frac{2}{3}$	1	750	3,750
10	10	19,200	$5\frac{1}{3}$	1	375	1,875
15	10	28,800	8	1	250	1,250
20	10	38,400	$10\frac{2}{3}$	1	$187\frac{1}{2}$	$937\frac{1}{2}$
30	100	57,600	16	1	1,250	6,250
40	100	76,800	$21\frac{1}{3}$	1	$937\frac{1}{2}$	$4,687\frac{1}{2}$
60	100	115,200	32	1	625	3,125
80	100	153,600	$42\frac{2}{3}$	1	$468\frac{3}{4}$	$2,343\frac{3}{4}$
100	100	192,000	$53\frac{1}{3}$	1	375	1,875
120	100	230,400	64	1	$312\frac{1}{2}$	$1,562\frac{1}{2}$
150	100	288,000	80	1	250	1,250
200	100	384,000	$106\frac{2}{3}$	1	$187\frac{1}{2}$	$937\frac{1}{2}$
300	1,000	576,000	160	1	1,250	6,250

WESTINGHOUSE TYPE C WATT-HOUR METERS

(*Continued*)

500 Volts, Polyphase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	12,000	3⅓	1	600	3,000
10	10	24,000	6⅔	1	300	1,500
15	10	36,000	10	1	200	1,000
20	10	48,000	13⅓	1	150	750
30	100	72,000	20	1	1,000	5,000
40	100	96,000	26⅔	1	750	3,750
60	100	144,000	40	1	500	2,500
80	100	192,000	53⅓	1	375	1,875
100	100	240,000	66⅔	1	300	1,500
120	100	288,000	80	1	250	1,250
150	100	360,000	100	1	200	1,000
200	100	480,000	133⅓	1	150	750
300	1,000	720,000	200	1	1,000	5,000

100 Volts, Y, 4-Wire, Three-Phase

5	10	4,800	1⅓	1	1,500	7,500
10	10	9,600	2⅔	1	750	3,750
15	10	14,400	4	1	500	2,500
20	10	19,200	5⅓	1	375	1,875
30	10	28,800	8	1	250	1,250
40	10	38,400	10⅔	1	187½	937½

WESTINGHOUSE TYPE C WATT-HOUR METERS
(*Continued*)

200 Volts, Y, 4-Wire, Three-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	9,600	2⅔	1	750	3,750
10	10	19,200	5⅓	1	375	1,875
15	10	28,800	8	1	250	1,250
20	10	38,400	10⅔	1	187½	937½
30	100	57,600	16	1	1,250	6,250
40	100	76,800	21⅓	1	937½	4,687½

400 Volts, Y, 4-Wire, Three-Phase

5	10	19,200	5⅓	1	375	1,875
10	10	38,400	10⅔	1	187½	937½
15	100	57,600	16	1	1,250	6,250
20	100	76,800	21⅓	1	937½	4,687½
30	100	115,200	32	1	625	3,125
40	100	153,600	42⅔	1	468¾	2,343¾

WESTINGHOUSE TYPE OA WATT-HOUR METERS

100 Volts, 2-Wire, Single-Phase

5	10	1,200	⅓	1	2,400	30,000
10	10	2,400	⅔	1	1,200	15,000

WESTINGHOUSE TYPE OA WATT-HOUR METERS
(*Continued*)

200 Volts, 2-Wire, Single Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	2,400	$\frac{2}{3}$	1	1,200	15,000
10	10	4,800	$1\frac{1}{3}$	1	600	7,500

100-200 Volts, 3-Wire, Single-Phase

5	10	2,400	$\frac{2}{3}$	1	1,200	15,000
10	10	4,800	$1\frac{1}{3}$	1	600	7,500

WESTINGHOUSE TYPE DC WATT-HOUR METERS

100 Volts, 2-Wire, Continuous Current
(Plain Meters)

5	10	1,200	$\frac{1}{3}$	1	4,836.9+	30,230.7+
$7\frac{1}{2}$	10	1,800	$\frac{1}{2}$	1	3,200	20,000
10	10	2,400	$\frac{2}{3}$	1	2,400	15,000
15	10	3,600	1	1	1,600	10,000
25	10	6,000	$1\frac{2}{3}$	1	960	6,000
50	10	12,000	$3\frac{1}{3}$	1	480	30,000
75	10	18,000	5	1	320	2,000
100	10	24,000	$6\frac{2}{3}$	1	240	1,500

WESTINGHOUSE TYPE DC WATT-HOUR METERS

(Continued)

200 Volts, 2-Wire, Continuous Current

(Plain Meters)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	2,400	$\frac{2}{3}$	1	2,400	15,000
$7\frac{1}{2}$	10	3,600	1	1	1,600	10,000
10	10	4,800	$1\frac{1}{3}$	1	1,200	7,500
15	10	7,200	2	1	800	5,000
25	10	12,000	$3\frac{1}{3}$	1	480	3,000
50	10	24,000	$6\frac{2}{3}$	1	240	1,500
75	10	36,000	10	1	160	1,000
100	10	48,000	$13\frac{1}{3}$	1	120	750

500 Volts, 2-Wire, Continuous Current

(Plain Meters)

5	10	6,000	$1\frac{2}{3}$	1	960	6,000
10	10	12,000	$3\frac{1}{3}$	1	480	3,000
15	10	18,000	5	1	320	2,000
25	10	30,000	$8\frac{1}{3}$	1	192	1,200
50	100	60,000	$16\frac{2}{3}$	1	960	6,000
100	100	120,000	$33\frac{1}{3}$	1	480	3,000

WESTINGHOUSE TYPE DC WATT-HOUR METERS

(*Continued*)

100-200 Volts, 3-Wire, Continuous Current

(Plain Meters)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	2,400	⅔	1	2,400	15,000
7½	10	3,600	1	1	1,600	10,000
10	10	4,800	1⅓	1	1,200	7,500
15	10	7,200	2	1	800	5,000
25	10	12,000	3⅓	1	480	3,000
50	10	24,000	6⅔	1	240	1,500
75	10	36,000	10	1	160	1,000
100	10	48,000	13⅓	1	120	750

100 Volts, 2-Wire, Continuous Current

(Sub A Meters)

5	10	1,200	⅓	1	6,000	30,000
7½	10	1,800	½	1	4,000	20,000
10	10	2,400	⅔	1	3,000	15,000
15	10	3,600	1	1	2,000	10,000
25	10	6,000	1⅔	1	1,200	6,000
50	10	12,000	3⅓	1	600	3,000
75	10	18,000	5	1	400	2,000
100	10	24,000	6⅔	1	300	1,500
150	10	36,000	10	1	200	1,000
200	10	48,000	13⅓	1	150	750
300	100	72,000	20	1	1,000	5,000
450	100	108,000	30	1	666⅔	3,333⅓

WESTINGHOUSE TYPE DC WATT-HOUR METERS
(*Continued*)

200 Volts, 2-Wire, Continuous Current (Sub A Meters)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	2,400	$\frac{2}{3}$	1	3,000	15,000
$7\frac{1}{2}$	10	3,600	1	1	2,000	10,000
10	10	4,800	$1\frac{1}{3}$	1	1,500	7,500
15	10	7,200	2	1	1,000	5,000
25	10	12,000	$3\frac{1}{3}$	1	600	3,000
50	10	24,000	$6\frac{2}{3}$	1	300	1,500
75	10	36,000	10	1	200	1,000
100	10	48,000	$13\frac{1}{3}$	1	150	750
150	100	72,000	20	1	1,000	5,000
200	100	96,000	$26\frac{2}{3}$	1	750	3,750
300	100	144,000	40	1	500	2,500
450	100	216,000	60	1	$333\frac{1}{3}$	$1,666\frac{2}{3}$

500 Volts, 2-Wire, Continuous Current (Sub A Meters)

5	10	6,000	$1\frac{2}{3}$	1	1,200	6,000
$7\frac{1}{2}$	10	9,000	$2\frac{1}{2}$	1	800	4,000
10	10	12,000	$3\frac{1}{3}$	1	600	3,000
15	10	18,000	5	1	400	2,000
25	10	30,000	$8\frac{1}{3}$	1	240	1,200
50	100	60,000	$16\frac{2}{3}$	1	1,200	6,000
75	100	90,000	25	1	800	4,000
100	100	120,000	$33\frac{1}{3}$	1	600	3,000
150	100	180,000	50	1	400	2,000
200	100	240,000	$66\frac{2}{3}$	1	300	1,500
300	100	360,000	100	1	200	1,000
450	1,000	540,000	150	1	$1,333\frac{1}{3}$	$6,666\frac{2}{3}$

WESTINGHOUSE TYPE DC WATT-HOUR METERS

(Continued)

100-200 Volts, 3-Wire, Continuous Current
(Sub A Meters)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	2,400	⅔	1	3,000	15,000
7½	10	3,600	1	1	2,000	10,000
10	10	4,800	1⅓	1	1,500	7,500
15	10	7,200	2	1	1,000	5,000
25	10	12,000	3⅓	1	600	3,000
50	10	24,000	6⅔	1	300	1,500
75	10	36,000	10	1	200	1,000
100	10	48,000	13⅓	1	150	750
150	100	72,000	20	1	1,000	5,000
200	100	96,000	26⅔	1	750	3,750
300	100	144,000	40	1	500	2,500

WESTINGHOUSE TYPE CW-6 WATT-HOUR METERS

100-110 Volts, 2-Wire, Continuous Current

		(Watt-hours)				
5	10	⅕	⅕	1	500	50,000
10	10	⅖	⅖	1	250	25,000
15	10	⅗	⅗	1	166⅔	16,666⅔
25	10	1	1	1	100	10,000
50	10	2	2	1	50	5,000

200-220 Volts, 2-Wire, Continuous Current

5	10	⅖	⅖	1	250	25,000
10	10	¾	¾	1	133⅓	13,333⅓
15	10	1¼	1¼	1	80	8,000
25	10	2	2	1	50	5,000
50	10	4	4	1	25	2,500

WESTINGHOUSE TYPE CW-6 WATT-HOUR METERS
(*Continued*)

200-220 Volts, 3-Wire, Continuous Current

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-hours)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	$\frac{2}{5}$	$\frac{2}{5}$	1	250	25,000
10	10	$\frac{3}{4}$	$\frac{3}{4}$	1	$133\frac{1}{3}$	$13,333\frac{1}{3}$
15	10	$1\frac{1}{4}$	$1\frac{1}{4}$	1	80	8,000
25	10	2	2	1	50	5,000
50	10	4	4	1	25	2,500

The standard formula for testing Fort Wayne watt-hour meters when using indicating instruments and a stop watch is

For Type K meters—single or polyphase

$$\text{Watts} = \frac{100 \times K_t \times R}{S}$$

For Types K1, K2, K3 and K4—single or polyphase

$$\text{Watts} = \frac{3{,}600 \times K_t \times R}{S}$$

in which

R = Number of complete revolutions of the moving element.
S = Number of seconds required for R revolutions.
K_t = Test Constant.
3,600 = Number of seconds in one hour.

In the literature pertaining to watt-hour meter testing distributed by the Fort Wayne Company, the testing formulas appear as follows:

For Type K meters—single or polyphase

$$\text{Watts} = \frac{100 \times C \times R}{S}$$

in which

R = Number of revolutions.
S = Number of seconds required to make revolutions.
C = Calibrating constant.
100 = Multiplier to avoid use of large calibrating constant.

For Types K1, K2, K3 and K4—single or polyphase.

$$\text{Watts} = \frac{3{,}600 \times C \times R}{S}$$

in which

R = Number of revolutions.
S = Number of seconds required to make revolutions.
C = Calibrating constant.
3,600 = Number of seconds in one hour.

FORT WAYNE TYPE K WATT-HOUR METERS

100-125 Volts, 2-Wire, Single-Phase
Below Serial No. 345,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand *	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r) *	Gear Ratio (R_g) *
5	10	9	¼	1	400	40,000
10	10	18	½	1	200	20,000
15	10	36	1	1	100	10,000
20	10	36	1	1	100	10,000
25	10	36	1	1	100	10,000
30	10	72	2	1	50	5,000
40	10	72	2	1	50	5,000
50	10	72	2	1	50	5,000
60	10	108	3	1	33⅓	3,333⅓
75	10	108	3	1	33⅓	3,333⅓
100	10	144	4	1	25	2,500
125	10	180	5	1	20	2,000
150	10	216	6	1	16⅔	1,666⅔
200	10	288	8	1	12½	1,250
250	10	360	10	1	10	1,000
300	10	540	15	1	6⅔	666⅔
400	10	720	20	1	5	500
600	10	1,080	30	10	33⅓	3,333⅓
800	10	1,440	40	10	25	2,500

* These values for meters reading kilowatt-hours only. Take $\frac{1}{10}$ of these values for meters reading in watt-hours.

FORT WAYNE TYPE K WATT-HOUR METERS (*Continued*)

100-125 Volts, 2-Wire, Single-Phase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	9	¼	1	400	40,000
10	10	18	½	1	200	20,000
15	10	27	¾	1	133⅓	13,333⅓
20	10	36	1	1	100	10,000
25	10	45	1¼	1	80	8,000
40	10	72	2	1	50	5,000
50	10	90	2½	1	40	4,000
75	10	135	3¾	1	26⅔	2,666⅔
100	10	180	5	1	20	2,000
125	10	225	6¼	1	16	1,600
150	10	270	7½	1	13⅓	1,333⅓
200	10	360	10	1	10	1,000
300	10	540	15	10	66⅔	6,666⅔
400	10	720	20	10	50	5,000
600	10	1,080	30	10	33⅓	3,333⅓
800	10	1,440	40	10	25	2,500

100-125 Volts, 2-Wire, Single-Phase
Above Serial No. 576,000

5	10	9	¼	1	400	40,000
10	10	18	½	1	200	20,000
15	10	27	¾	1	133⅓	13,333⅓
20	10	36	1	1	100	10,000
25	10	45	1¼	1	80	8,000
40	10	72	2	1	50	5,000
50	10	90	2½	1	40	4,000
75	10	135	3¾	1	26⅔	2,666⅔
100	10	180	5	10	200	20,000
125	10	225	6¼	10	160	16,000
150	10	270	7½	10	133⅓	13,333⅓
200	10	360	10	10	100	10,000
300	10	540	15	10	66⅔	6,666⅔
400	10	720	20	10	50	5,000
600	10	1,080	30	10	33⅓	3,333⅓
800	10	1,440	40	10	25	2,500

FORT WAYNE TYPE K WATT-HOUR METERS

(Continued)

200-250 Volts, 2-Wire, Single-Phase

Below Serial No. 345,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand *	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r) *	Gear Ratio (R_g) *
5	10	18	½	1	200	20,000
10	10	36	1	1	100	10,000
15	10	54	1½	1	66⅔	6,666⅔
20	10	72	2	1	50	5,000
25	10	72	2	1	50	5,000
30	10	90	2½	1	40	4,000
40	10	108	3	1	33⅓	3,333⅓
50	10	144	4	1	25	2,500
60	10	180	5	1	20	2,000
75	10	216	6	1	16⅔	1,666⅔
100	10	288	8	1	12½	1,250
125	10	360	10	1	10	1,000
150	10	432	12	1	8⅓	833⅓
200	10	576	16	1	6¼	625
250	10	720	20	1	5	500
300	10	1,080	30	10	33⅓	3,333⅓
400	10	1,440	40	10	25	2,500
600	10	2,160	60	10	16⅔	1,666⅔
800	10	2,880	80	10	12½	1,250

* These values for meters reading in kilowatt-hours only. Take $\frac{1}{10}$ of these values for meters reading in watt-hours.

FORT WAYNE TYPE K WATT-HOUR METERS (*Continued*)

200-250 Volts, 2-Wire, Single-Phase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	18	½	1	200	20,000
10	10	36	1	1	100	10,000
15	10	54	1½	1	66⅔	6,666⅔
20	10	72	2	1	50	5,000
25	10	90	2½	1	40	4,000
40	10	144	4	1	25	2,500
50	10	180	5	1	20	2,000
75	10	270	7½	1	13⅓	1,333⅓
100	10	360	10	1	10	1,000
125	10	450	12½	10	80	8,000
150	10	540	15	10	66⅔	6,666⅔
200	10	720	20	10	50	5,000
300	10	1,080	30	10	33⅓	3,333⅓
400	10	1,440	40	10	25	2,500
600	10	2,160	60	10	16⅔	1,666⅔
800	10	2,880	80	10	12½	1,250

200-250 Volts, 2-Wire, Single-Phase
Above Serial No. 576,000

5	10	18	½	1	200	20,000
10	10	36	1	1	100	10,000
15	10	54	1½	1	66⅔	6,666⅔
20	10	72	2	1	50	5,000
25	10	90	2½	1	40	4,000
40	10	144	4	1	25	2,500
50	10	180	5	10	200	20,000
75	10	270	7½	10	133⅓	13,333⅓
100	10	360	10	10	100	10,000
125	10	450	12½	10	80	8,000
150	10	540	15	10	66⅔	6,666⅔
200	10	720	20	10	50	5,000
300	10	1,080	30	10	33⅓	3,333⅓
400	10	1,440	40	10	25	2,500
600	10	2,160	60	100	166⅔	16,666⅔
800	10	2,880	80	100	125	12,500

FORT WAYNE TYPE K WATT-HOUR METERS (*Continued*)

400-499 Volts, 2-Wire, Single-Phase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	36	1	1	100	10,000
10	10	72	2	1	50	5,000
15	10	108	3	1	33⅓	3,333⅓
20	10	144	4	1	25	2,500
25	10	180	5	1	20	2,000
40	10	288	8	1	12½	1,250
50	10	360	10	1	10	1,000
75	10	540	15	10	66⅔	6,666⅔
100	10	720	20	10	50	5,000
125	10	900	25	10	40	4,000
150	10	1,080	30	10	33⅓	3,333⅓
200	10	1,440	40	10	25	2,500
300	10	2,160	60	10	16⅔	1,666⅔
400	10	2,880	80	10	12½	1,250
600	10	4,320	120	100	83⅓	8,333⅓
800	10	5,760	160	100	62½	6,250

400-499 Volts, 2-Wire, Single-Phase
Above Serial No. 576,000

5	10	36	1	1	100	10,000
10	10	72	2	1	50	5,000
15	10	108	3	1	33⅓	3,333⅓
20	10	144	4	1	25	2,500
25	10	180	5	10	200	20,000
40	10	288	8	10	125	12,500
50	10	360	10	10	100	10,000
75	10	540	15	10	66⅔	6,666⅔
100	10	720	20	10	50	5,000
125	10	900	25	10	40	4,000
150	10	1,080	30	10	33⅓	3,333⅓
200	10	1,440	40	10	25	2,500
300	10	2,160	60	100	166⅔	16,666⅔
400	10	2,880	80	100	125	12,500
600	10	4,320	120	100	83⅓	8,333⅓
800	10	5,760	160	100	62½	6,250

FORT WAYNE TYPE K WATT-HOUR METERS
(Continued)

500-625 Volts, 2-Wire, Single-Phase

Below Serial No. 345,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand *	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r) *	Gear Ratio (R_g) *
5	10	45	1¼	1	80	8,000
10	10	90	2½	1	40	4,000
15	10	180	5	1	20	2,000
20	10	180	5	1	20	2,000
25	10	180	5	1	20	2,000
30	10	360	10	1	10	1,000
40	10	360	10	1	10	1,000
50	10	360	10	1	10	1,000
60	10	540	15	1	6⅔	666⅔
75	10	540	15	1	6⅔	666⅔
100	10	720	20	1	5	500
125	10	900	25	1	4	400
150	10	1,080	30	10	33⅓	3,333⅓
200	10	1,440	40	10	25	2,500
250	10	1,800	50	10	20	2,000
300	10	2,700	75	10	13⅓	1,333⅓
400	10	3,600	100	10	10	1,000
600	10	5,400	150	10	6⅔	666⅔
800	10	7,200	200	10	5	500

* These values for meters reading in kilowatt-hours only. Take $\frac{1}{10}$ of these values for meters reading in watt-hours.

FORT WAYNE TYPE K WATT-HOUR METERS (*Continued*)

500-625 Volts, 2-Wire, Single-Phase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	45	1¼	1	80	8,000
10	10	90	2½	1	40	4,000
15	10	135	3¾	1	26⅔	2,666⅔
20	10	180	5	1	20	2,000
25	10	225	6¼	1	16	1,600
40	10	360	10	1	10	1,000
50	10	450	12½	10	80	8,000
75	10	675	18¾	10	53⅓	5,333⅓
100	10	900	25	10	40	4,000
125	10	1,125	31¼	10	32	3,200
150	10	1,350	37½	10	26⅔	2,666⅔
200	10	1,800	50	10	20	2,000
300	10	2,700	75	10	13⅓	1,333⅓
400	10	3,600	100	10	10	1,000
600	10	5,400	150	100	66⅔	6,666⅔
800	10	7,200	200	100	50	5,000

500-625 Volts, 2-Wire, Single-Phase
Above Serial No. 576,000

5	10	45	1¼	1	80	8,000
10	10	90	2½	1	40	4,000
15	10	135	3¾	1	26⅔	2,666⅔
20	10	180	5	10	200	20,000
25	10	225	6¼	10	160	16,000
40	10	360	10	10	100	10,000
50	10	450	12½	10	80	8,000
75	10	675	18¾	10	53⅓	5,333⅓
100	10	900	25	10	40	4,000
125	10	1,125	31¼	10	32	3,200
150	10	1,350	37½	10	26⅔	2,666⅔
200	10	1,800	50	100	200	20,000
300	10	2,700	75	100	133⅓	13,333⅓
400	10	3,600	100	100	100	10,000
600	10	5,400	150	100	66⅔	6,666⅔
800	10	7,200	200	100	50	5,000

FORT WAYNE TYPE K WATT-HOUR METERS (*Continued*)

200-250 Volts, 3-Wire, Single-Phase
Below Serial No. 345,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand *	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r) *	Gear Ratio (R_g) *
5	10	18	½	1	200	20,000
10	10	36	1	1	100	10,000
15	10	54	1½	1	66⅔	6,666⅔
20	10	72	2	1	50	5,000
25	10	72	2	1	50	5,000
30	10	90	2½	1	40	4,000
40	10	108	3	1	33⅓	3,333⅓
50	10	144	4	1	25	2,500
60	10	180	5	1	20	2,000
75	10	216	6	1	16⅔	1,666⅔
100	10	288	8	1	12½	1,250
125	10	360	10	1	10	1,000
150	10	432	12	1	8⅓	833⅓

* These values for meters reading in kilowatt-hours only. Take $\frac{1}{10}$ of these values for meters reading in watt-hours.

200-250 Volts, 3-Wire, Single-Phase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

5	10	18	½	1	200	20,000
10	10	36	1	1	100	10,000
15	10	54	1½	1	66⅔	6,666⅔
20	10	72	2	1	50	5,000
25	10	90	2½	1	40	4,000
40	10	144	4	1	25	2,500
50	10	180	5	1	20	2,000
75	10	270	7½	1	13⅓	1,333⅓
100	10	360	10	1	10	1,000
125	10	450	12½	10	80	8,000
150	10	540	15	10	66⅔	6,666⅔

FORT WAYNE TYPE K WATT-HOUR METERS (*Continued*)

200-250 Volts, 3-Wire, Single-Phase
Above Serial No. 576,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	18	½	1	200	20,000
10	10	36	1	1	100	10,000
15	10	54	1½	1	66⅔	6,666⅔
20	10	72	2	1	50	5,000
25	10	90	2½	1	40	4,000
40	10	144	4	1	25	2,500
50	10	180	5	10	200	20,000
75	10	270	7½	10	133⅓	13,333⅓
100	10	360	10	10	100	10,000
125	10	450	12½	10	80	8,000
150	10	540	15	10	66⅔	6,666⅔

100-125 Volts, Polyphase
Below Serial No. 345,000

5	10	36	1	1	100	10,000
10	10	72	2	1	50	5,000
15	10	108	3	1	33⅓	3,333⅓
20	10	144	4	1	25	2,500
25	10	144	4	1	25	2,500
30	10	216	6	1	16⅔	1,666⅔
40	10	288	8	1	12½	1,250
50	10	288	8	1	12½	1,250
60	10	432	12	1	8⅓	833⅓
75	10	432	12	1	8⅓	833⅓
100	10	576	16	1	6¼	625
125	10	720	20	1	5	500
150	10	864	24	1	4⅙	416⅔
200	10	1,440	40	10	25	2,500
300	10	2,160	60	10	16⅔	1,666⅔
400	10	2,880	80	10	12½	1,250
600	10	4,320	120	10	8⅓	833⅓
800	10	5,760	160	10	6¼	625

FORT WAYNE TYPE K WATT-HOUR METERS (*Continued*)

100-125 Volts, Polyphase

Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	36	1	1	100	10,000
10	10	72	2	1	50	5,000
15	10	108	3	1	33⅓	3,333⅓
20	10	144	4	1	25	2,500
25	10	180	5	1	20	2,000
40	10	288	8	1	12½	1,250
50	10	360	10	1	10	1,000
75	10	540	15	10	66⅔	6,666⅔
100	10	720	20	10	50	5,000
125	10	900	25	10	40	4,000
150	10	1,080	30	10	33⅓	3,333⅓
200	10	1,440	40	10	25	2,500
300	10	2,160	60	10	16⅔	1,666⅔
400	10	2,880	80	10	12½	1,250
600	10	4,320	120	100	83⅓	8,333⅓
800	10	5,760	160	100	62½	6,250

FORT WAYNE TYPE K WATT-HOUR METERS
(*Continued*)

200-250 Volts, Polyphase

Below Serial No. 345,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	72	2	1	50	5,000
10	10	144	4	1	25	2,500
15	10	216	6	1	16⅔	1,666⅔
20	10	288	8	1	12½	1,250
25	10	288	8	1	12½	1,250
30	10	360	10	1	10	1,000
40	10	576	16	1	6¼	625
50	10	576	16	1	6¼	625
60	10	864	24	1	4⅙	416⅔
75	10	864	24	1	4⅙	416⅔
100	10	1,152	32	1	3⅛	312½
125	10	1,440	40	10	25	2,500
150	10	1,800	50	10	20	2,000
200	10	2,880	80	10	12½	1,250
300	10	4,320	120	10	8⅓	833⅓
400	10	5,760	160	10	6¼	625
600	10	8,640	240	10	4⅙	416⅔
800	10	11,520	320	10	3⅛	312½

FORT WAYNE TYPE K WATT-HOUR METERS
(*Continued*)

200-250 Volts, Polyphase

Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	72	2	1	50	5,000
10	10	144	4	1	25	2,500
15	10	216	6	1	16⅔	1,666⅔
20	10	288	8	1	12½	1,250
25	10	360	10	1	10	1,000
40	10	576	16	10	62½	6,250
50	10	720	20	10	50	5,000
75	10	1,080	30	10	33⅓	3,333⅓
100	10	1,440	40	10	25	2,500
125	10	1,800	50	10	20	2,000
150	10	2,160	60	10	16⅔	1,666⅔
200	10	2,880	80	10	12½	1,250
300	10	4,320	120	100	83⅓	8,333⅓
400	10	5,760	160	100	62½	6,250
600	10	8,640	240	100	41⅔	4,166⅔
800	10	11,520	320	100	31¼	3,125

FORT WAYNE TYPE K WATT-HOUR METERS
(*Continued*)

400-499 Volts, Polyphase

Below Serial No. 345,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	144	4	1	25	2,500
10	10	288	8	1	12½	1,250
15	10	432	12	1	8⅓	833⅓
20	10	576	16	1	6¼	625
25	10	576	16	1	6¼	625
30	10	720	20	1	5	500
40	10	1,152	32	1	3⅛	312½
50	10	1,152	32	1	3⅛	312½
60	10	1,728	48	10	20⅚	2,083⅓
75	10	1,728	48	10	20⅚	2,083⅓
100	10	2,304	64	10	15⅝	1,562½
125	10	2,880	80	10	12½	1,250
150	10	3,600	100	10	10	1,000
200	10	5,760	160	10	6¼	625
300	10	8,640	240	10	4⅙	416⅔
400	10	11,520	320	10	3⅛	312½
600	10	17,280	480	100	20⅚	2,083⅓
800	10	23,040	640	100	15⅝	1,562½

FORT WAYNE TYPE K WATT-HOUR METERS
(*Continued*)

400-499 Volts, Polyphase

Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	144	4	1	25	2,500
10	10	288	8	1	12½	1,250
15	10	432	12	10	83⅓	8,333⅓
20	10	576	16	10	62½	6,250
25	10	720	20	10	50	5,000
40	10	1,152	32	10	31¼	3,125
50	10	1,440	40	10	25	2,500
75	10	2,160	60	10	16⅔	1,666⅔
100	10	2,880	80	10	12½	1,250
125	10	3,600	100	10	10	1,000
150	10	4,320	120	100	83⅓	8,333⅓
200	10	5,760	160	100	62½	6,250
300	10	8,640	240	100	41⅔	4,166⅔
400	10	11,520	320	100	31¼	3,125
600	10	17,280	480	100	20⅚	2,083⅓
800	10	23,040	640	100	15⅝	1,562½

FORT WAYNE TYPE K WATT-HOUR METERS
(*Continued*)

500-625 Volts, Polyphase

Below Serial No. 345,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	180	5	1	20	2,000
10	10	360	10	1	10	1,000
15	10	540	10½	1	6⅔	666⅔
20	10	720	20	1	5	500
25	10	720	20	1	5	500
30	10	1,080	30	10	33⅓	3,333⅓
40	10	1,440	40	10	25	2,500
50	10	1,440	40	10	25	2,500
60	10	2,160	60	10	16⅔	1,666⅔
75	10	2,160	60	10	16⅔	1,666⅔
100	10	2,880	80	10	12½	1,250
125	10	3,600	100	10	10	1,000
150	10	4,320	120	10	8⅓	833⅓
200	10	7,200	200	10	5	500
300	10	10,800	300	100	33⅓	3,333⅓
400	10	14,400	400	100	25	2,500
600	10	21,600	600	100	16⅔	1,666⅔
800	10	28,800	800	100	12½	1,250

FORT WAYNE TYPE K WATT-HOUR METERS
(*Continued*)

500-625 Volts, Polyphase

Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	180	5	1	20	2,000
10	10	360	10	1	10	1,000
15	10	540	15	10	66⅔	6,666⅔
20	10	720	20	10	50	5,000
25	10	900	25	10	40	4,000
40	10	1,440	40	10	25	2,500
50	10	1,800	50	10	20	2,000
75	10	2,700	75	10	13⅓	1,333⅓
100	10	3,600	100	10	10	1,000
125	10	4,500	125	100	80	8,000
150	10	5,400	150	100	66⅔	6,666⅔
200	10	7,200	200	100	50	5,000
300	10	10,800	300	100	33⅓	3,333⅓
400	10	14,400	400	100	25	2,500
600	10	21,600	600	100	16⅔	1,666⅔
800	10	28,800	800	100	12½	1,250

FORT WAYNE TYPES K1, K2 AND K3 WATT-HOUR METERS

100-125 Volts, 2-Wire, Single-Phase

Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1/4	1/4	1	400	40,000
10	10	1/2	1/2	1	200	20,000
15	10	3/4	3/4	1	133 1/3	13,333 1/3
20	10	1	1	1	100	10,000
25	10	1 1/4	1 1/4	1	80	8,000
40	10	2	2	1	50	5,000
50	10	2 1/2	2 1/2	1	40	4,000
75	10	3 3/4	3 3/4	1	26 2/3	2,666 2/3
100	10	5	5	1	20	2,000
125	10	6 1/4	6 1/4	1	16	1,600
150	10	7 1/2	7 1/2	1	13 1/3	1,333 1/3
200	10	10	10	1	10	1,000
300	10	15	15	10	66 2/3	6,666 2/3
400	10	20	20	10	50	5,000
600	10	30	30	10	33 1/3	3,333 1/3
800	10	40	40	10	25	2,500

FORT WAYNE TYPES K1, K2 AND K3 WATT-HOUR METERS (*Continued*)

100-125 Volts, 2-Wire, Single-Phase Above Serial No. 576,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	¼	¼	1	400	40,000
10	10	½	½	1	200	20,000
15	10	¾	¾	1	133⅓	13,333⅓
20	10	1	1	1	100	10,000
25	10	1¼	1¼	1	80	8,000
40	10	2	2	1	50	5,000
50	10	2½	2½	1	40	4,000
75	10	3¾	3¾	1	26⅔	2,666⅔
100	10	5	5	10	200	20,000
125	10	6¼	6¼	10	160	16,000
150	10	7½	7½	10	133⅓	13,333⅓
200	10	10	10	10	100	10,000
300	10	15	15	10	66⅔	6,666⅔
400	10	20	20	10	50	5,000
600	10	30	30	10	33⅓	3,333⅓
800	10	40	40	10	25	2,500

200-250 Volts, 2-Wire, Single-Phase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

5	10	½	½	1	200	20,000
10	10	1	1	1	100	10,000
15	10	1½	1½	1	66⅔	6,666⅔
20	10	2	2	1	50	5,000
25	10	2½	2½	1	40	4,000
40	10	4	4	1	25	2,500
50	10	5	5	1	20	2,000
75	10	7½	7½	1	13⅓	1,333⅓
100	10	10	10	1	10	1,000
125	10	12½	12½	10	80	8,000
150	10	15	15	10	66⅔	6,666⅔
200	10	20	20	10	50	5,000
300	10	30	30	10	33⅓	3.333⅓
400	10	40	40	10	25	2,500
600	10	60	60	10	16⅔	1,666⅔
800	10	80	80	10	12½	1,250

FORT WAYNE TYPES K1, K2 AND K3 WATT-HOUR METERS
(Continued)

200-250 Volts, 2-Wire, Single-Phase Above Serial No. 576,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	½	½	1	200	20,000
10	10	1	1	1	100	10,000
15	10	1½	1½	1	66⅔	6,666⅔
20	10	2	2	1	50	5,000
25	10	2½	2½	1	40	4,000
40	10	4	4	1	25	2,500
50	10	5	5	10	200	20,000
75	10	7½	7½	10	133⅓	13,333⅓
100	10	10	10	10	100	10,000
125	10	12½	12½	10	80	8,000
150	10	15	15	10	66⅔	6,666⅔
200	10	20	20	10	50	5,000
300	10	30	30	10	33⅓	3,333⅓
400	10	40	40	10	25	2,500
600	10	60	60	100	166⅔	16,666⅔
800	10	80	80	100	125	12,500

400-499 Volts, 2-Wire, Single-Phase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

5	10	1	1	1	100	10,000
10	10	2	2	1	50	5,000
15	10	3	3	1	33⅓	3,333⅓
20	10	4	4	1	25	2,500
25	10	5	5	1	20	2,000
40	10	8	8	1	12½	1,250
50	10	10	10	1	10	1,000
75	10	15	15	10	66⅔	6,666⅔
100	10	20	20	10	50	5,000
125	10	25	25	10	40	4,000
150	10	30	30	10	33⅓	3,333⅓
200	10	40	40	10	25	2,500
300	10	60	60	10	16⅔	1,666⅔
400	10	80	80	10	12½	1,250
600	10	120	120	100	83⅓	8,333⅓
800	10	160	160	100	62½	6,250

FORT WAYNE TYPES K1, K2 AND K3 WATT-HOUR METERS
(Continued)

400-499 Volts, 2-Wire, Single-Phase — Above Serial No. 576,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1	1	1	100	10,000
10	10	2	2	1	50	5,000
15	10	3	3	1	33⅓	3,333⅓
20	10	4	4	1	25	2,500
25	10	5	5	10	200	20,000
40	10	8	8	10	125	12,500
50	10	10	10	10	100	10,000
75	10	15	15	10	66⅔	6,666⅔
100	10	20	20	10	50	5,000
125	10	25	25	10	40	4,000
150	10	30	30	10	33⅓	3,333⅓
200	10	40	40	10	25	2,500
300	10	60	60	100	166⅔	16,666⅔
400	10	80	80	100	125	12,500
600	10	120	120	100	83⅓	8,333⅓
800	10	160	160	100	62½	6,250

500-625 Volts, 2-Wire, Single-Phase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1¼	1¼	1	80	8,000
10	10	2½	2½	1	40	4,000
15	10	3¾	3¾	1	26⅔	2,666⅔
20	10	5	5	1	20	2,000
25	10	6¼	6¼	1	16	1,600
40	10	10	10	1	10	1,000
50	10	12½	12½	10	80	8,000
75	10	18¾	18¾	10	53⅓	5,333⅓
100	10	25	25	10	40	4,000
125	10	31¼	31¼	10	32	3,200
150	10	37½	37½	10	26⅔	2,666⅔
200	10	50	50	10	20	2,000
300	10	75	75	10	13⅓	1,333⅓
400	10	100	100	10	10	1,000
600	10	150	150	100	66⅔	6,666⅔
800	10	200	200	100	50	5,000

FORT WAYNE TYPES K1, K2 AND K3 WATT-HOUR METERS
(Continued)

500-625 Volts, 2-Wire, Single-Phase — Above Serial No. 576,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1¼	1¼	1	80	8,000
10	10	2½	2½	1	40	4,000
15	10	3¾	3¾	1	26⅔	2,666⅔
20	10	5	5	10	200	20,000
25	10	6¼	6¼	10	160	16,000
40	10	10	10	10	100	10,000
50	10	12½	12½	10	80	8,000
75	10	18¾	18¾	10	53⅓	5,333⅓
100	10	25	25	10	40	4,000
125	10	31¼	31¼	10	32	3,200
150	10	37½	37½	10	26⅔	2,666⅔
200	10	50	50	100	200	20,000
300	10	75	75	100	133⅓	13,333⅓
400	10	100	100	100	100	10,000
600	10	150	150	100	66⅔	6,666⅔
800	10	200	200	100	50	5,000

200-250 Volts, 3-Wire, Single-Phase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	½	½	1	200	20,000
10	10	1	1	1	100	10,000
15	10	1½	1½	1	66⅔	6,666⅔
20	10	2	2	1	50	5,000
25	10	2½	2½	1	40	4,000
40	10	4	4	1	25	2,500
50	10	5	5	1	20	2,000
75	10	7½	7½	1	13⅓	1,333⅓
100	10	10	10	1	10	1,000
125	10	12½	12½	10	80	8,000
150	10	15	15	10	66⅔	6,666⅔
200	10	20	20	10	50	5,000
300	10	30	30	10	33⅓	3,333⅓
400	10	40	40	10	25	2,500
600	10	60	60	10	16⅔	1,666⅔
800	10	80	80	10	12½	1,250

FORT WAYNE TYPES K1, K2 AND K3 WATT-HOUR METERS (*Continued*)

200-250 Volts, 3-Wire, Single-Phase

Above Serial No. 576,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	½	½	1	200	20,000
10	10	1	1	1	100	10,000
15	10	1½	1½	1	66⅔	6,666⅔
20	10	2	2	1	50	5,000
25	10	2½	2½	1	40	4,000
40	10	4	4	1	25	2,500
50	10	5	5	10	200	20,000
75	10	7½	7½	10	133⅓	13,333⅓
100	10	10	10	10	100	10,000
125	10	12½	12½	10	80	8,000
150	10	15	15	10	66⅔	6,666⅔
200	10	20	20	10	50	5,000
300	10	30	30	10	33⅓	3,333⅓
400	10	40	40	10	25	2,500
600	10	60	60	100	166⅔	16,666⅔
800	10	80	80	100	125	12,500

FORT WAYNE TYPE K1 WATT-HOUR METERS

100-125 Volts, Polyphase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1	1	1	100	10,000
10	10	2	2	1	50	5,000
15	10	3	3	1	33⅓	3,333⅓
20	10	4	4	1	25	2,500
25	10	5	5	1	20	2,000
40	10	8	8	1	12½	1,250
50	10	10	10	1	10	1,000
75	10	15	15	10	66⅔	6,666⅔
100	10	20	20	10	50	5,000
125	10	25	25	10	40	4,000
150	10	30	30	10	33⅓	3,333⅓
200	10	40	40	10	25	2,500
300	10	60	60	10	16⅔	1,666⅔
400	10	80	80	10	12½	1,250
600	10	120	120	100	83⅓	8,333⅓
800	10	160	160	100	62½	6,250

100-125 Volts, Polyphase
Above Serial No. 576,000

5	10	1	1	1	100	10,000
10	10	2	2	1	50	5,000
15	10	3	3	1	33⅓	3,333⅓
20	10	4	4	1	25	2,500
25	10	5	5	1	20	2,000
40	10	8	8	1	12½	1,250
50	10	10	10	1	10	1,000
75	10	15	15	10	66⅔	6,666⅔
100	10	20	20	10	50	5,000
125	10	25	25	10	40	4,000
150	10	30	30	10	33⅓	3,333⅓
200	10	40	40	10	25	2,500
300	10	60	60	10	16⅔	1,666⅔
400	10	80	80	10	12½	1,250
600	10	120	120	100	83⅓	8,333⅓
800	10	160	160	100	62½	6,250

FORT WAYNE TYPE K1 WATT-HOUR METERS (*Continued*)

200-250 Volts, Polyphase

Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	2	2	1	50	5,000
10	10	4	4	1	25	2,500
15	10	6	6	1	16⅔	1,666⅔
20	10	8	8	1	12½	1,250
25	10	10	10	1	10	1,000
40	10	16	16	10	62½	6,250
50	10	20	20	10	50	5,000
75	10	30	30	10	33⅓	3,333⅓
100	10	40	40	10	25	2,500
125	10	50	50	10	20	2,000
150	10	60	60	10	16⅔	1,666⅔
200	10	80	80	10	12½	1,250
300	10	120	120	100	83⅓	8,333⅓
400	10	160	160	100	62½	6,250
600	10	240	240	100	41⅔	4,166⅔
800	10	320	320	100	31¼	3,125

200-250 Volts, Polyphase

Above Serial No. 576,000

5	10	2	2	1	50	5,000
10	10	4	4	1	25	2,500
15	10	6	6	1	16⅔	1,666⅔
20	10	8	8	1	12½	1,250
25	10	10	10	1	10	1,000
40	10	16	16	10	62½	6,250
50	10	20	20	10	50	5,000
75	10	30	30	10	33⅓	3,333⅓
100	10	40	40	10	25	2,500
125	10	50	50	10	20	2,000
150	10	60	60	10	16⅔	1,666⅔
200	10	80	80	10	12½	1,250
300	10	120	120	100	83⅓	8,333⅓
400	10	160	160	100	62½	6,250
600	10	240	240	100	41⅔	4,166⅔
800	10	320	320	100	31¼	3,125

FORT WAYNE TYPE K1 WATT-HOUR METERS (*Continued*)

400-499 Volts, Polyphase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	4	4	1	25	2,500
10	10	8	8	1	12½	1,250
15	10	12	12	10	83⅓	8,333⅓
20	10	16	16	10	62½	6,250
25	10	20	20	10	50	5,000
40	10	32	32	10	31¼	3,125
50	10	40	40	10	25	2,500
75	10	60	60	10	16⅔	1,666⅔
100	10	80	80	10	12½	1,250
125	10	100	100	10	10	1,000
150	10	120	120	100	83⅓	8,333⅓
200	10	160	160	100	62½	6,250
300	10	240	240	100	41⅔	4,166⅔
400	10	320	320	100	31¼	3,125
600	10	480	480	100	20⅚	2,083⅓
800	10	640	640	100	15⅝	1,562½

400-499 Volts, Polyphase
Above Serial No. 576,000

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	4	4	1	25	2,500
10	10	8	8	1	12½	1,250
15	10	12	12	10	83⅓	8,333⅓
20	10	16	16	10	62½	6,250
25	10	20	20	10	50	5,000
40	10	32	32	10	31¼	3,125
50	10	40	40	10	25	2,500
75	10	60	60	10	16⅔	1,666⅔
100	10	80	80	10	12½	1,250
125	10	100	100	10	10	1,000
150	10	120	120	100	83⅓	8,333⅓
200	10	160	160	100	62½	6,250
300	10	240	240	100	41⅔	4,166⅔
400	10	320	320	100	31¼	3,125
600	10	480	480	100	20⅚	2,083⅓
800	10	640	640	100	15⅝	1,562½

FORT WAYNE TYPE K1 WATT-HOUR METERS (*Continued*)

500-625 Volts, Polyphase
Between Serial No. 345,000 and 576,000 (Both Inclusive)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	5	5	1	20	2,000
10	10	10	10	1	10	1,000
15	10	15	15	10	$66\frac{2}{3}$	$6{,}666\frac{2}{3}$
20	10	20	20	10	50	5,000
25	10	25	25	10	40	4,000
40	10	40	40	10	25	2,500
50	10	50	50	10	20	2,000
75	10	75	75	10	$13\frac{1}{3}$	$1{,}333\frac{1}{3}$
100	10	100	100	10	10	1,000
125	10	125	125	100	80	8,000
150	10	150	150	100	$66\frac{2}{3}$	$6{,}666\frac{2}{3}$
200	10	200	200	100	50	5,000
300	10	300	300	100	$33\frac{1}{3}$	$3{,}333\frac{1}{3}$
400	10	400	400	100	25	2,500
600	10	600	600	100	$16\frac{2}{3}$	$1{,}666\frac{2}{3}$
800	10	800	800	100	$12\frac{1}{2}$	1,250

500-625 Volts, Polyphase
Above Serial No. 576,000.

5	10	5	5	1	20	2,000
10	10	10	10	1	10	1,000
15	10	15	15	10	$66\frac{2}{3}$	$6{,}666\frac{2}{3}$
20	10	20	20	10	50	5,000
25	10	25	25	10	40	4,000
40	10	40	40	10	25	2,500
50	10	50	50	10	20	2,000
75	10	75	75	10	$13\frac{1}{3}$	$1{,}333\frac{1}{3}$
100	10	100	100	10	10	1,000
125	10	125	125	100	80	8,000
150	10	150	150	100	$66\frac{2}{3}$	$6{,}666\frac{2}{3}$
200	10	200	200	100	50	5,000
300	10	300	300	100	$33\frac{1}{3}$	$3{,}333\frac{1}{3}$
400	10	400	400	100	25	2,500
600	10	600	600	100	$16\frac{2}{3}$	$1{,}666\frac{2}{3}$
800	10	800	800	100	$12\frac{1}{2}$	1,250

FORT WAYNE TYPE K3 WATT-HOUR METERS

100-125 Volts, Polyphase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	½	½	1	200	20,000
10	10	1	1	1	100	10,000
15	10	1½	1½	1	66⅔	6,666⅔
20	10	2	2	1	50	5,000
25	10	2½	2½	1	40	4,000
30	10	3	3	1	33⅓	3,333⅓
40	10	4	4	1	25	2,500
50	10	5	5	10	200	20,000
60	10	6	6	10	166⅔	16,666⅔
75	10	7½	7½	10	133⅓	13,333⅓
80	10	8	8	10	125	12,500
100	10	10	10	10	100	10,000
125	10	12½	12½	10	80	8,000
150	10	15	15	10	66⅔	6,666⅔
200	10	20	20	10	50	5,000
300	10	30	30	10	33⅓	3,333⅓
400	10	40	40	10	25	2,500
600	10	60	60	100	166⅔	16,666⅔
800	10	80	80	100	125	12,500

200-250 Volts, Polyphase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1	1	1	100	10,000
10	10	2	2	1	50	5,000
15	10	3	3	1	33⅓	3,333⅓
20	10	4	4	1	25	2,500
25	10	5	5	10	200	20,000
30	10	6	6	10	166⅔	16,666⅔
40	10	8	8	10	125	12,500
50	10	10	10	10	100	10,000
60	10	12	12	10	83⅓	8,333⅓
75	10	15	15	10	66⅔	6,666⅔

FORT WAYNE TYPE K3 WATT-HOUR METERS (*Continued*)

200-250 Volts, Polyphase (*Continued*)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
80	10	16	16	10	$62\frac{1}{2}$	6,250
100	10	20	20	10	50	5,000
125	10	25	25	10	40	4,000
150	10	30	30	10	$33\frac{1}{3}$	$3,333\frac{1}{3}$
200	10	40	40	10	25	2,500
300	10	60	60	100	$166\frac{2}{3}$	$16,666\frac{2}{3}$
400	10	80	80	100	125	12,500
600	10	120	120	100	$83\frac{1}{3}$	$8,333\frac{1}{3}$
800	10	160	160	100	$62\frac{1}{2}$	6,250

400-499 Volts, Polyphase

5	10	2	2	1	50	5,000
10	10	4	4	1	25	2,500
15	10	6	6	10	$166\frac{2}{3}$	$16,666\frac{2}{3}$
20	10	8	8	10	125	12,500
25	10	10	10	10	100	10,000
30	10	12	12	10	$83\frac{1}{3}$	$8,333\frac{1}{3}$
40	10	16	16	10	$62\frac{1}{2}$	6,250
50	10	20	20	10	50	5,000
60	10	24	24	10	$41\frac{2}{3}$	$4,166\frac{2}{3}$
75	10	30	30	10	$33\frac{1}{3}$	$3,333\frac{1}{3}$
80	10	32	32	10	$31\frac{1}{4}$	3,125
100	10	40	40	10	25	2,500
125	10	50	50	100	200	20,000
150	10	60	60	100	$166\frac{2}{3}$	$16,666\frac{2}{3}$
200	10	80	80	100	125	12,500
300	10	120	120	100	$83\frac{1}{3}$	$8,333\frac{1}{3}$
400	10	160	160	100	$62\frac{1}{2}$	6,250
600	10	240	240	100	$41\frac{2}{3}$	$4,166\frac{2}{3}$
800	10	320	320	100	$31\frac{1}{4}$	3,125

FORT WAYNE TYPE K3 WATT-HOUR METERS (*Continued*)

500-625 Volts, Polyphase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	2½	2½	1	40	4,000
10	10	5	5	10	200	20,000
15	10	7½	7½	10	133⅓	13,333⅓
20	10	10	10	10	100	10,000
25	10	12½	12½	10	80	8,000
30	10	15	15	10	66⅔	6,666⅔
40	10	20	20	10	50	5,000
50	10	25	25	10	40	4,000
60	10	30	30	10	33⅓	3,333⅓
75	10	37½	37½	10	26⅔	2,666⅔
80	10	40	40	10	25	2,500
100	10	50	50	100	200	20,000
125	10	62½	62½	100	160	16,000
150	10	75	75	100	133⅓	13,333⅓
200	10	100	100	100	100	10,000
300	10	150	150	100	66⅔	6,666⅔
400	10	200	200	100	50	5,000
600	10	300	300	100	33⅓	3,333⅓
800	10	400	400	100	25	2,500

FORT WAYNE TYPE K4 WATT-HOUR METERS

100-125 Volts, 2-Wire, Single-Phase

5	10	¼	¼	1	400	40,000
10	10	½	½	1	200	20,000
15	10	¾	¾	1	133⅓	13,333⅓
20	10	1	1	1	100	10,000
25	10	1¼	1¼	1	80	8,000

FORT WAYNE TYPE K4 WATT-HOUR METERS (*Continued*)

200-250 Volts, 2-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	½	½	1	200	20,000
10	10	1	1	1	100	10,000
15	10	1½	1½	1	66⅔	6,666⅔
20	10	2	2	1	50	5,000
25	10	2½	2½	1	40	4,000

200-250 Volts, 3-Wire, Single-Phase

5	10	½	½	1	200	20,000
10	10	1	1	1	100	10,000
15	10	1½	1½	1	66⅔	6,666⅔
20	10	2	2	1	50	5,000
25	10	2½	2½	1	40	4,000

The formula for testing all types and capacities of Sangamo watt-hour meters when using indicating instruments and a stop watch is

$$\text{Watts} = \frac{R \times K_t}{S}$$

in which

R = Number of complete revolutions of the moving element.
S = Number of seconds required for R revolutions.
K_t = Test constant.

In the literature pertaining to watt-hour meter testing distributed by the Sangamo Company, the testing formula appears as follows:

$$\text{Watts} = \frac{R \times K}{T}$$

in which

R = Number of revolutions.
T = Number of seconds.
K = Constant.

SANGAMO TYPE D CONTINUOUS CURRENT WATT-HOUR METERS

110 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	2,400	⅔	1	300	15,000
10	10	2,400	⅔	1	300	15,000
20	10	4,800	1⅓	1	150	7,500
30	10	7,200	2	1	100	5,000
40	10	9,600	2⅔	1	75	3,750
60	10	14,400	4	1	50	2,500
80	10	19,200	5⅓	1	37½	1,875
100	10	24,000	6⅔	1	30	1,500
150	10	36,000	10	1	20	1,000
200	10	48,000	13⅓	1	15	750
300	10	72,000	20	1	10	500
400	10	96,000	26⅔	1	7½	375
500	10	120,000	33⅓	1	6	300
600	10	144,000	40	1	5	250
800	10	192,000	53⅓	10	37½	1,875
1,000	10	240,000	66⅔	10	30	1,500

220 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	4,800	1⅓	1	150	7,500
10	10	4,800	1⅓	1	150	7,500
20	10	9,600	2⅔	1	75	3,750
30	10	14,400	4	1	50	2,500
40	10	19,200	5⅓	1	37½	1,875
60	10	28,800	8	1	25	1,250
80	10	38,400	10⅔	1	18¾	937½
100	10	48,000	13⅓	1	15	750
150	10	72,000	20	1	10	500
200	10	96,000	26⅔	1	7½	375
300	10	144,000	40	1	5	250
400	10	192,000	53⅓	10	37½	1,875
500	10	240,000	66⅔	10	30	1,500
600	10	288,000	80	10	25	1,250
800	10	384,000	106⅔	10	18¾	937½
1,000	10	480,000	133⅓	10	15	750

SANGAMO TYPE D CONTINUOUS CURRENT WATT-HOUR METERS (*Continued*)

500 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	12,000	$3\frac{1}{3}$	1	60	3,000
10	10	12,000	$3\frac{1}{3}$	1	60	3,000
20	10	24,000	$6\frac{2}{3}$	1	30	1,500
30	10	36,000	10	1	20	1,000
40	10	48,000	$13\frac{1}{3}$	1	15	750
60	10	72,000	20	1	10	500
80	10	96,000	$26\frac{2}{3}$	1	$7\frac{1}{2}$	375
100	10	120,000	$33\frac{1}{3}$	1	6	300
150	10	180,000	50	10	40	2,000
200	10	240,000	$66\frac{2}{3}$	10	30	1,500
300	10	360,000	100	10	20	1,000
400	10	480,000	$133\frac{1}{3}$	10	15	750
500	10	600,000	$166\frac{2}{3}$	10	12	600
600	10	720,000	200	10	10	500
800	10	960,000	$266\frac{2}{3}$	10	$7\frac{1}{2}$	375
1,000	10	1,200,000	$333\frac{1}{3}$	10	6	300

600 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	14,400	4	1	50	2,500
10	10	14,400	4	1	50	2,500
20	10	28,800	8	1	25	1,250
30	10	43,200	12	1	$16\frac{2}{3}$	$833\frac{1}{3}$
40	10	57,600	16	1	$12\frac{1}{2}$	625
60	10	86,400	24	1	$8\frac{1}{3}$	$416\frac{2}{3}$
80	10	115,200	32	1	$6\frac{1}{4}$	$312\frac{1}{2}$
100	10	144,000	40	1	5	250
150	10	216,000	60	10	$33\frac{1}{3}$	$1,666\frac{2}{3}$
200	10	288,000	80	10	25	1,250
300	10	432,000	120	10	$16\frac{2}{3}$	$833\frac{1}{3}$
400	10	576,000	160	10	$12\frac{1}{2}$	625
500	10	720,000	200	10	10	500
600	10	864,000	240	10	$8\frac{1}{3}$	$416\frac{2}{3}$
800	10	1,152,000	320	10	$6\frac{1}{4}$	$312\frac{1}{2}$
1,000	10	1,440,000	400	10	5	250

SANGAMO TYPE F SINGLE-PHASE WATT-HOUR METERS

110 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1,800	$\frac{1}{2}$	1	400	20,000
10	10	2,400	$\frac{2}{3}$	1	300	15,000
20	10	4,800	$1\frac{1}{3}$	1	150	7,500
30	10	7,200	2	1	100	5,000
40	10	9,600	$2\frac{2}{3}$	1	75	3,750
60	10	14,400	4	1	50	2,500
80	10	19,200	$5\frac{1}{3}$	1	$37\frac{1}{2}$	1,875
100	10	24,000	$6\frac{2}{3}$	1	30	1,500
150	10	36,000	10	1	20	1,000
200	10	48,000	$13\frac{1}{3}$	1	15	750
300	10	72,000	20	1	10	500
400	10	96,000	$26\frac{2}{3}$	1	$7\frac{1}{2}$	375
500	10	120,000	$33\frac{1}{3}$	1	6	300
600	10	144,000	40	1	5	250
800	10	192,000	$53\frac{1}{3}$	10	$37\frac{1}{2}$	1,875
1,000	10	240,000	$66\frac{2}{3}$	10	30	1,500

200 Volts, 2-Wire

5	10	3,600	1	1	200	10,000
10	10	4,800	$1\frac{1}{3}$	1	150	7,500
20	10	9,600	$2\frac{2}{3}$	1	75	3,750
30	10	14,400	4	1	50	2,500
40	10	19,200	$5\frac{1}{3}$	1	$37\frac{1}{2}$	1,875
60	10	28,800	8	1	25	1,250
80	10	38,400	$10\frac{2}{3}$	1	$18\frac{3}{4}$	$937\frac{1}{2}$
100	10	48,000	$13\frac{1}{3}$	1	15	750
150	10	72,000	20	1	10	500
200	10	96,000	$26\frac{2}{3}$	1	$7\frac{1}{2}$	375
300	10	144,000	40	1	5	250
400	10	192,000	$53\frac{1}{3}$	10	$37\frac{1}{2}$	1,875
500	10	240,000	$66\frac{2}{3}$	10	30	1,500
600	10	288,000	80	10	25	1,250
800	10	384,000	$106\frac{2}{3}$	10	$18\frac{3}{4}$	$937\frac{1}{2}$
1,000	10	480,000	$133\frac{1}{3}$	10	15	750

SANGAMO TYPE F SINGLE-PHASE WATT-HOUR METERS
(*Continued*)

110-220 Volts, 3-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	3,600	1	1	200	10,000
10	10	4,800	1⅓	1	150	7,500
20	10	9,600	2⅔	1	75	3,750
30	10	14,400	4	1	50	2,500
40	10	19,200	5⅓	1	37½	1,875
60	10	28,800	8	1	25	1,250
80	10	38,400	10⅔	1	18¾	937½
100	10	48,000	13⅓	1	15	750
150	10	72,000	20	1	10	500
200	10	96,000	26⅔	1	7½	375
300	10	144,000	40	1	5	250
400	10	192,000	53⅓	10	37½	1,875
500	10	240,000	66⅔	10	30	1,500
600	10	288,000	80	10	25	1,250
800	10	384,000	106⅔	10	18¾	937½
1,000	10	480,000	133⅓	10	15	750

SANGAMO TYPE H SINGLE-PHASE WATT-HOUR METERS

110 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	750	$\frac{5}{24}$	1	960	48,000
10	10	1,500	$\frac{5}{12}$	1	480	24,000
20	10	3,000	$\frac{5}{8}$	1	240	12,000
30	10	4,500	$1\frac{1}{4}$	1	160	8,000
40	10	6,000	$1\frac{2}{3}$	1	120	6,000
60	10	9,000	$2\frac{1}{2}$	1	80	4,000
80	10	12,000	$3\frac{1}{3}$	1	60	3,000
100	10	15,000	$4\frac{1}{6}$	1	48	2,400
150	10	22,500	$6\frac{1}{4}$	1	32	1,600
200	10	30,000	$8\frac{1}{3}$	1	24	1,200
300	10	45,000	$12\frac{1}{2}$	10	160	8.000
400	10	60,000	$16\frac{2}{3}$	10	120	6.000
500	10	75,000	$20\frac{5}{6}$	10	96	4,800
600	10	90,000	25	10	80	4,000
800	10	120,000	$33\frac{1}{3}$	10	60	3,000
1,000	10	150,000	$41\frac{2}{3}$	10	48	2,400

220 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1,500	$\frac{5}{12}$	1	480	24,000
10	10	3,000	$\frac{5}{8}$	1	240	12,000
20	10	6,000	$1\frac{2}{3}$	1	120	6,000
30	10	9,000	$2\frac{1}{2}$	1	80	4,000
40	10	12,000	$3\frac{1}{3}$	1	60	3,000
60	10	18,000	5	1	40	2,000
80	10	24,000	$6\frac{2}{3}$	1	30	1,500
100	10	30,000	$8\frac{1}{3}$	1	24	1,200
150	10	45,000	$12\frac{1}{2}$	10	160	8,000
200	10	60,000	$16\frac{2}{3}$	10	120	6,000
300	10	90,000	25	10	80	4,000
400	10	120,000	$33\frac{1}{3}$	10	60	3,000
500	10	150,000	$41\frac{2}{3}$	10	48	2,400
600	10	180,000	50	10	40	2,000
800	10	240,000	$66\frac{2}{3}$	10	30	1,500
1,000	10	300,000	$83\frac{1}{3}$	10	24	1,200

SANGAMO TYPE H SINGLE-PHASE WATT-HOUR METERS

(*Continued*)

110-120 Volts, 3-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1,500	$\frac{5}{12}$	1	480	24,000
10	10	3,000	$\frac{5}{6}$	1	240	12,000
20	10	6,000	$1\frac{2}{3}$	1	120	6,000
30	10	9,000	$2\frac{1}{2}$	1	80	4,000
40	10	12,000	$3\frac{1}{3}$	1	60	3,000
60	10	18,000	5	1	40	2,000
80	10	24,000	$6\frac{2}{3}$	1	30	1,500
100	10	30,000	$8\frac{1}{3}$	1	24	1,200
150	10	45,000	$12\frac{1}{2}$	10	160	8,000
200	10	60,000	$16\frac{2}{3}$	10	120	6,000
300	10	90,000	25	10	80	4,000
400	10	120,000	$33\frac{1}{3}$	10	60	3,000
500	10	150,000	$41\frac{2}{3}$	10	48	2,400
600	10	180,000	50	10	40	2,000
800	10	240,000	$66\frac{2}{3}$	10	30	1,500
1,000	10	300,000	$83\frac{1}{3}$	10	24	1,200

On account of the many special purposes for which **ampere-hour** meters are used, and the various types of recording **trains** which it has been found necessary to build for these purposes, the data on these trains cannot be given exactly in the same way as for standard watt-hour meters. Given herewith is a table containing the **data for ampere-hour meters** compiled in the same form as that for watt-hour meters, so far as is possible to do so. The numerical value of one revolution of the first dial hand, the register constant, the gear ratio, etc., cannot be given, however, in the same way as given for watt-hour meters.

Recording trains, or **registers,** as used **on Sangamo ampere-hour meters,** are of **three general types:**

(1) **Standard 4-dial register,** as used on Sangamo Type D watt-hour meters. These are used on meters where it is desired to keep a record of total charge or discharge, but not both.

Meters with such dials are usually used in pairs on loads subject to rapid reversals, and each meter is equipped with detent on shaft to prevent backward movement of dials.

(2) **Duplex recording trains,** register having two rows of four dials each, one for charge and one for discharge, the gearing for each row being arranged so that when one set of dials is recording the other is stopped.

(3) **Register with large circular dial,** 3½ inches in diameter, reading in various unit values of ampere-hours per revolution, dial having one hundred divisions, every tenth division being heavy, and numbered.

A sub-type is a register with large dial, and within it, below the center of main dial a row of four totalizing dials, reading from left to right, instead of from right to left, like other dials. (This came about through certain difficulties in gearing up for the totalizing train.)

The totalizing dials are arranged to record total discharge or charge, but not both, being geared to move when large hand is moving in one direction, but held by a detent when it reverses.

This type of register is also made to record in various units proportional to ampere-hours, such as weights of metals for electroplating, and ampere squared-hours for measuring losses in conductors, and may be provided with resetting, alarm giving and circuit opening features, all of which are described in Chapter XVI.

The test constant is the same for a given capacity meter, irrespective of the type of register used, but the register constants, register ratios and gear ratios vary according to the type of register as noted on the table following.

NOTE: With duplex trains, if both charge and discharge dials are arranged to read in ampere-hours, the values in the table apply to both, but if charge row is geared to read in kilowatt-hours at normal charging voltage, say 120, the first right-hand dial in the charge row reads 10 kilowatt-hours per revolution in all capacities up to and including 200 amperes.

TABLE OF DATA FOR SANGAMO AMPERE-HOUR METERS

Capacity in Amperes	Amp. Hrs. per Rev. of Disk	Amp. Secs. per Rev. of Disk	Amp. Hrs. per Rev. of 1st Dial Hand	Register Constant	Register Ratio	Gear Ratio
10	$\frac{1}{100}$	36	100	10	200	10,000
20	$\frac{1}{50}$	72	100	10	100	5,000
30	$\frac{3}{100}$	108	100	10	$66\frac{2}{3}$	$3,333\frac{1}{3}$
40	$\frac{1}{25}$	144	100	10	50	2,500
60	$\frac{3}{50}$	216	100	10	$33\frac{1}{3}$	$1,666\frac{2}{3}$
80	$\frac{2}{25}$	288	100	10	25	1,250
100	$\frac{1}{10}$	360	100	10	20	1,000
150	$\frac{3}{20}$	540	100	10	$13\frac{1}{3}$	$666\frac{2}{3}$
200	$\frac{1}{5}$	720	100	10	10	500
300	$\frac{3}{10}$	1,080	1,000	100	$66\frac{2}{3}$	$333\frac{1}{3}$

Larger sizes have proportional values.

Above values are for types (1) and (2) registers, as per notes herewith.

In case of type (3) registers, with large circular dials, the large dial may have any desired standard value for one revolution of the hand thus reading direct 100, 200, 300, 400, 500 or 600 ampere-hours to a revolution, and each tenth division being numbered accordingly. For larger values, a register constant of 10 is employed.

From the preceding it is evident that the register ratio and the gear ratio, for type (3) registers, will be variables, as the dial value has no definite relation to the meter capacity.

When totalizing dials are present, these are always geared so that the first left-hand dial reads 100 ampere-hours per revolution, irrespective of the value of large dial, unless the latter is greater than 600, in which case reading of totalizing dials must be multiplied by 10.

The standard formula for testing all types and capacities of Duncan watt-hour meters when using indicating instruments and a stop watch is

$$\text{Watts} = \frac{3{,}600 \times K_t \times R}{S}$$

in which

R = Number of complete revolutions of the moving element.
S = Number of seconds required for R revolutions.
K_t = Test constant.
3,600 = Number of seconds in one hour.

In the literature pertaining to watt-hour meter testing distributed by the Duncan Electric Manufacturing Company, the testing formula appears as follows:

$$\text{Watts} = \frac{\text{Revolutions} \times 3{,}600 \times \text{Testing Constant}}{\text{Seconds during Test}}$$

DUNCAN MODEL A WATT-HOUR METERS

110 Volts, 2-Wire

(Serial Numbers Less Than 76,000) (5-DIAL METERS)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
2½	1	¼	¼	1	40	4,000
5	1	¼	¼	1	40	4,000
7½	1	½	½	1	20	2,000
10	1	½	½	1	20	2,000
15	1	1	1	1	10	1,000
25	1	1	1	1	10	1,000
50	1	2	2	1	5	500
75	1	3	3	1	3⅓	333⅓
100	1	4	4	10	25	2,500
150	1	6	6	10	16⅔	1,666⅔
200	1	8	8	10	12½	1,250
300	1	12	12	10	8⅓	833⅓
450	1	20	20	10	5	500
600	1	25	25	10	4	400
800	1	30	30	10	3⅓	333⅓
1,000	1	40	40	100	25	2,500
1,200	1	50	50	100	20	2,000
1,500	1	60	60	100	16⅔	1,666⅔
2,000	1	80	80	100	12½	1,250
2,500	1	100	100	100	10	1,000
3,000	1	120	120	100	8⅓	833⅓
4,000	1	160	160	100	6¼	625
5,000	1	200	200	100	5	500
6,000	1	250	250	100	4	400
8,000	1	300	300	100	3⅓	333⅓
10,000	1	400	400	1,000	25	2,500
12,000	1	500	500	1,000	20	2,000
15,000	1	600	600	1,000	16⅔	1,666⅔

DUNCAN MODEL A WATT-HOUR METERS (*Continued*)

500 Volts, 2-Wire

(Serial Numbers Less Than 76,000) (5-DIAL METERS)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
2½	1	1	1	1	10	1,000
5	1	1	1	1	10	1,000
7½	1	2	2	1	5	500
10	1	2	2	1	5	500
15	1	5	5	10	20	2,000
25	1	5	5	10	20	2,000
50	1	10	10	10	10	1,000
75	1	16	16	10	6¼	625
100	1	20	20	10	5	500
150	1	30	30	10	3⅓	333⅓
200	1	40	40	100	25	2,500
300	1	60	60	100	16⅔	1,666⅔
450	1	80	80	100	12½	1,250
600	1	100	100	100	10	1,000
800	1	160	160	100	6¼	625
1,000	1	200	200	100	5	500
1,200	1	250	250	100	4	400
1,500	1	300	300	100	3⅓	333⅓
2,000	1	400	400	1,000	25	2,500
2,500	1	500	500	1,000	20	2,000
3,000	1	600	600	1,000	16⅔	1,666⅔
4,000	1	800	800	1,000	12½	1,250
5,000	1	1,000	1,000	1,000	10	1,000
6,000	1	1,200	1,200	1,000	8⅓	833⅓
8,000	1	1,600	1,600	1,000	6¼	625
10,000	1	2,500	2,500	1,000	4	400
12,000	1	2,500	2,500	1,000	4	400
15,000	1	3,000	3,000	1,000	3⅓	333⅓

DUNCAN MODEL A WATT-HOUR METERS (*Continued*)

220 Volts, 2- & 3-Wire

(Serial Numbers Less Than 76,000) (5-DIAL METERS)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
2½	1	½	½	1	20	2,000
5	1	½	½	1	20	2,000
7½	1	1	1	1	10	1,000
10	1	1	1	1	10	1,000
15	1	2	2	1	5	500
25	1	2	2	1	5	500
50	1	4	4	10	25	2,500
75	1	6	6	10	16⅔	1,666⅔
100	1	8	8	10	12½	1,250
150	1	12	12	10	8⅓	833⅓
200	1	16	16	10	6¼	625
300	1	25	25	10	4	400
450	1	40	40	100	25	2,500
600	1	50	50	100	20	2,000
800	1	60	60	100	16⅔	1,666⅔
1,000	1	80	80	100	12½	1,250
1,200	1	100	100	100	10	1,000
1,500	1	120	120	100	8⅓	833⅓
2,000	1	160	160	100	6¼	625
2,500	1	200	200	100	5	500
3,000	1	250	250	100	4	400
4,000	1	300	300	100	3⅓	333⅓
5,000	1	400	400	1,000	25	2,500
6,000	1	500	500	1,000	20	2,000
8,000	1	800	800	1,000	12½	1,250
10,000	1	1,200	1,200	1,000	8⅓	833⅓
12,000	1	1,200	1,200	1,000	8⅓	833⅓
15,000	1	1,600	1,600	1,000	6¼	625

DUNCAN MODEL E WATT-HOUR METERS

110 Volts, 2-Wire

(Serial Numbers 76,000 to 150,000) (4-DIAL METERS)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
2½	10	⅛	⅛	1	800	80,000
5	10	¼	¼	1	400	40,000
7½	10	½	½	1	200	20,000
10	10	½	½	1	200	20,000
15	10	1	1	1	100	10,000
25	10	1	1	1	100	10,000
50	10	2	2	1	50	5,000
75	10	3	3	1	33⅓	3,333⅓
100	10	4	4	1	25	2,500
150	10	6	6	1	16⅔	1,666⅔
200	10	8	8	1	12½	1,250
300	10	12	12	1	8⅓	833⅓
450	10	20	20	10	50	5,000
600	10	25	25	1	4	400
800	10	40	40	10	25	2,500
1,000	10	40	40	10	25	2,500
1,200	10	50	50	10	20	2,000
1,500	10	60	60	10	16⅔	1,666⅔
2,000	10	100	100	100	100	1,000
2,500	10	120	120	10	8⅓	833⅓
3,000	10	160	160	10	6¼	625
4,000	10	200	200	100	50	5,000
5,000	10	250	250	10	4	400
6,000	10	300	300	10	3⅓	333⅓
8,000	10	300	300	10	3⅓	333⅓
10,000	10	400	400	100	25	2,500
12,000	10	500	500	100	20	2,000
15,000	10	600	600	100	16⅔	1,666⅔

DUNCAN MODEL E WATT-HOUR METERS (*Continued*)

110 Volts, 2-Wire

(Serial Numbers larger than 150,000) (4-DIAL METERS)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
2½	10	.125	.125	1	800	80,000
5	10	.25	.25	1	400	40,000
7½	10	.375	.375	1	266⅔	26,666⅔
10	10	.5	.5	1	200	20,000
15	10	.75	.75	1	133⅓	13,333⅓
25	10	1.25	1.25	10	800	80,000
50	10	2.5	2.5	10	400	40,000
75	10	3.75	3.75	10	266⅔	26,666⅔
100	10	5.	5.	10	200	20,000
150	10	7.5	7.5	10	133⅓	13,333⅓
200	10	10.	10.	10	100	10,000
300	10	15.	15.	10	66⅔	6,666⅔
400	10	20.	20.	10	50	5,000
450	10	22.5	22.5	10	44$\frac{4}{9}$	4,444$\frac{4}{9}$
500	10	25.	25.	10	40	4,000
600	10	30.	30.	10	33⅓	3,333⅓
800	10	40.	40.	100	250	25,000
1,000	10	50.	50.	100	200	20,000
1,200	10	60.	60.	100	166⅔	16,666⅔
1,500	10	75.	75.	100	133⅓	13,333⅓
2,000	10	100.	100.	100	100	10,000
2,500	10	125.	125.	100	80	8,000
3,000	10	150.	150.	100	66⅔	6,666⅔
4,000	10	200.	200.	100	50	5,000
5,000	10	250.	250.	100	40	4,000
6,000	10	300.	300.	100	33⅓	3,333⅓
8,000	10	400.	400.	100	25	2,500
10,000	10	500.	500.	1,000	200	20,000
12,000	10	600.	600.	1,000	166⅔	16,666⅔
15,000	10	750.	750.	1,000	133⅓	13,333⅓
20,000	10	1,000.	1,000.	1,000	100	10,000

DUNCAN MODEL E WATT-HOUR METERS (*Continued*)

500 Volts, 2-Wire

(Serial Numbers 76,000 to 150,000) (4-DIAL METERS)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
2½	10	½	½	1	200	20,000
5	10	1	1	1	100	10,000
7½	10	2	2	1	50	5,000
10	10	2	2	1	50	5,000
15	10	5	5	1	20	2,000
25	10	5	5	1	20	2,000
50	10	10	10	10	100	10,000
75	10	16	16	1	6¼	625
100	10	20	20	10	50	5,000
150	10	30	30	1	3⅓	333⅓
200	10	40	40	10	25	2,500
300	10	60	60	10	16⅔	1,666⅔
450	10	100	100	100	100	10,000
600	10	120	120	10	8⅓	833⅓
800	10	160	160	10	6¼	625
1,000	10	200	200	100	50	5,000
1,200	10	250	250	10	4	400
1,500	10	300	300	10	3⅓	333⅓
2,000	10	400	400	100	25	2,500
2,500	10	500	500	100	20	2,000
3,000	10	600	600	100	16⅔	1,666⅔
4,000	10	800	800	100	12½	1,250
5,000	10	1,200	1,200	100	8⅓	833⅓
6,000	10	1,200	1,200	100	8⅓	833⅓
8,000	10	1,600	1,600	100	6¼	625
10,000	10	2,500	2,500	100	4	400
12,000	10	2,500	2,500	100	4	400
15,000	10	3,000	3,000	100	3⅓	333⅓

DUNCAN MODEL E WATT-HOUR METERS (*Continued*)

500 Volts, 2-Wire

(Serial Numbers larger than 150,000) (4-DIAL METERS)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
2½	10	.625	.625	1	160	16,000
5	10	1.25	1.25	1	80	8,000
7½	10	1.875	1.875	1	53⅓	5,333⅓
10	10	2.5	2.5	1	40	4,000
15	10	3.75	3.75	10	266⅔	26,666⅔
25	10	6.25	6.25	10	160	16,000
50	10	12.5	12.5	10	80	8,000
75	10	18.75	18.75	10	53⅓	5,333⅓
100	10	25.	25.	10	40	4,000
150	10	37.5	37.5	100	266⅔	26,666⅔
200	10	50.	50.	100	200	20,000
300	10	75.	75.	100	133⅓	13,333⅓
400	10	100.	100.	100	100	10,000
450	10	112.5	112.5	100	$88\frac{8}{9}$	$8,888\frac{8}{9}$
500	10	125.	125.	100	80	8,000
600	10	150.	150.	100	66⅔	6,666⅔
800	10	200.	200.	100	50	5,000
1,000	10	250.	250.	100	40	4,000
1,200	10	300.	300.	100	33⅓	3,333⅓
1,500	10	375.	375.	1,000	266⅔	26,666⅔
2,000	10	500.	500.	1,000	200	20,000
2,500	10	625.	625.	1,000	160	16,000
3,000	10	750.	750.	1,000	133⅓	13,333⅓
4,000	10	1,000.	1,000.	1,000	100	10,000
5,000	10	1,250.	1,250.	1,000	80	8,000
6,000	10	1,500.	1,500.	1,000	66⅔	6,666⅔
8,000	10	2,000.	2,000.	1,000	50	5,000
10,000	10	2,500.	2,500.	1,000	40	4,000
12,000	10	3,000.	3,000.	1,000	33⅓	3,333⅓
15,000	10	3,750.	3,750.	10,000	266⅔	26,666⅔
20,000	10	5,000.	5,000.	10,000	200	20,000

DUNCAN MODEL E WATT-HOUR METERS (*Continued*)

220 Volts, 2 & 3-Wire

(Serial Numbers 76,000 to 150,000) (4-DIAL METERS)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
2½	10	¼	¼	1	400	40,000
5	10	½	½	1	200	20,000
7½	10	1	1	1	100	10,000
10	10	1	1	1	100	10,000
15	10	2	2	1	50	5,000
25	10	2	2	1	50	5,000
50	10	4	4	1	25	2,500
75	10	6	6	1	16⅔	1,666⅔
100	10	8	8	1	12½	1,250
150	10	12	12	1	8⅓	833⅓
200	10	16	16	1	6¼	625
300	10	25	25	1	4	400
450	10	40	40	10	25	2,500
600	10	50	50	10	20	2,000
800	10	80	80	10	12½	1,250
1,000	10	100	100	100	100	10,000
1,200	10	120	120	10	8⅓	833⅓
1,500	10	160	160	10	6¼	625
2,000	10	200	200	100	50	5,000
2,500	10	250	250	10	4	400
3,000	10	300	300	10	3⅓	333⅓
4,000	10	400	400	100	25	2,500
5,000	10	500	500	100	20	2,000
6,000	10	600	600	100	16⅔	1,666⅔
8,000	10	800	800	100	12½	1,250
10,000	10	1,200	1,200	100	8⅓	833⅓
12,000	10	1,200	1,200	100	8⅓	833⅓
15,000	10	1,600	1,600	100	6¼	625

DUNCAN MODEL E WATT-HOUR METERS (*Continued*)

220 Volts, 2 & 3-Wire

(Serial Numbers larger than 150,000) (4-DIAL METERS)

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
2½	10	.25	.25	1	400	40,000
5	10	.5	.5	1	200	20,000
7½	10	.75	.75	1	133⅓	13,333⅓
10	10	1.	1.	1	100	10,000
15	10	1.5	1.5	1	66⅔	6,666⅔
25	10	2.5	2.5	10	400	40,000
50	10	5.	5.	10	200	20,000
75	10	7.5	7.5	10	133⅓	13,333⅓
100	10	10.	10.	10	100	10,000
150	10	15.	15.	10	66⅔	6,666⅔
200	10	20.	20.	10	50	5,000
300	10	30.	30.	10	33⅓	3,333⅓
400	10	40.	40.	10	25	2,500
450	10	45.	45.	10	22 2/9	2,222 2/9
500	10	50.	50.	100	200	20,000
600	10	60.	60.	100	166⅔	16,666⅔
800	10	80.	80.	100	125	12,500
1,000	10	100.	100.	100	100	10,000
1,200	10	120.	120.	100	83⅓	8,333⅓
1,500	10	150.	150.	100	66⅔	6,666⅔
2,000	10	200.	200.	100	50	5,000
2,500	10	250.	250.	100	40	4,000
3,000	10	300.	300.	100	33⅓	3,333⅓
4,000	10	400.	400.	100	25	2,500
5,000	10	500.	500.	1,000	200	20,000
6,000	10	600.	600.	1,000	166⅔	16,666⅔
8,000	10	800.	800.	1,000	125	12,500
10,000	10	1,000.	1,000.	1,000	100	10,000
12,000	10	1,200.	1,200.	1,000	83⅓	8,333⅓
15,000	10	1,500.	1,500.	1,000	66⅔	6,666⅔
20,000	10	2,000.	2,000.	1,000	50	5,000

DUNCAN MODEL M WATT-HOUR METERS

110 Volts, 2-Wire, Single-Phase
60 to 133 Cycles

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	.25	.25	1	400	40,000
10	10	.5	.5	1	200	20,000
15	10	.75	.75	1	133⅓	13,333⅓
20	10	1.	1.	1	100	10,000
25	10	1.25	1.25	10	800	80,000
50	10	2.5	2.5	10	400	40,000
75	10	3.75	3.75	10	266⅔	26,666⅔
100	10	5.	5.	10	200	20,000
150	10	7.5	7.5	10	133⅓	13,333⅓
200	10	10.	10.	10	100	10,000
300	10	15.	15.	10	66⅔	6,666⅔
400	10	20.	20.	10	50	5,000
500	10	25.	25.	10	40	4,000

220 Volts, 2-Wire, Single-Phase
60 to 133 Cycles

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	.5	.5	1	200	20,000
10	10	1.	1.	1	100	10,000
15	10	1.5	1.5	1	66⅔	6,666⅔
20	10	2.	2.	1	50	5,000
25	10	2.5	2.5	10	400	40,000
50	10	5.	5.	10	200	20,000
75	10	7.5	7.5	10	133⅓	13,333⅓
100	10	10.	10.	10	100	10,000
150	10	15.	15.	10	66⅔	6,666⅔
200	10	20.	20.	10	50	5,000
300	10	30.	30.	10	33⅓	3,333⅓
400	10	40.	40.	10	25	2,500
500	10	50.	50.	100	200	20,000

DUNCAN MODEL M WATT-HOUR METERS (*Continued*)

220 Volts, 3-Wire, Single-Phase
60 to 133 Cycles

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	.5	.5	1	200	20,000
10	10	1.	1.	1	100	10,000
15	10	1.5	1.5	1	66⅔	6,666⅔
20	10	2.	2.	1	50	5,000
25	10	2.5	2.5	10	400	40,000
50	10	5.	5.	10	200	20,000
75	10	7.5	7.5	10	133⅓	13,333⅓
100	10	10.	10.	10	100	10,000
150	10	15.	15.	10	66⅔	6,666⅔
200	10	20.	20.	10	50	5,000
300	10	30.	30.	10	33⅓	3,333⅓
400	10	40.	40.	10	25	2,500
500	10	50.	50.	100	200	20,000

The standard formula for testing all types and capacities of Columbia watt-hour meters when using indicating instruments and a stop watch is

$$\text{Watts} = \frac{R \times K_t}{S}$$

in which

R = Number of complete revolutions of the moving element.
S = Number of seconds required for R revolutions.
K_t = Test constant.

In the literature pertaining to watt-hour meter testing distributed by the Columbia Meter Company, the testing formula appears as follows:

$$\text{Watts} = \frac{\text{Rev.} \times K}{\text{Sec.}}$$

in which

Rev. = Number of revolutions.
Sec. = Number of seconds.
K = Test constant.

COLUMBIA CONTINUOUS CURRENT TYPE D WATT-HOUR METERS

100 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1,000	$\frac{5}{18}$	1	360	36,000
10	10	2,000	$\frac{5}{9}$	1	180	18,000
15	10	3,000	$\frac{5}{6}$	1	120	12,000
25	10	5,000	$1\frac{7}{18}$	1	72	7,200
50	10	10,000	$2\frac{7}{9}$	1	36	3,600
75	10	15,000	$4\frac{1}{6}$	1	24	2,400
100	100	20,000	$5\frac{5}{9}$	1	180	18,000
150	100	30,000	$8\frac{1}{3}$	1	120	12,000
200	100	40,000	$11\frac{1}{9}$	1	90	9,000
300	100	60,000	$16\frac{2}{3}$	1	60	6,000

200 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
$2\frac{1}{2}$	10	1,000	$\frac{5}{18}$	1	360	36,000
5	10	2,000	$\frac{5}{9}$	1	180	18,000
$7\frac{1}{2}$	10	4,000	$1\frac{1}{9}$	1	90	9,000
10	10	4,000	$1\frac{1}{9}$	1	90	9,000
15	10	6,000	$1\frac{2}{3}$	1	60	6,000
25	10	10,000	$2\frac{7}{9}$	1	36	3,600
50	100	20,000	$5\frac{5}{9}$	1	180	18,000
75	100	30,000	$8\frac{1}{3}$	1	120	12,000
100	100	40,000	$11\frac{1}{9}$	1	90	9,000
150	100	60,000	$16\frac{2}{3}$	1	60	6,000
200	100	80,000	$22\frac{2}{9}$	1	45	4,500
300	100	120,000	$33\frac{1}{3}$	1	30	3,000

COLUMBIA CONTINUOUS CURRENT TYPE D WATT-HOUR METERS (*Continued*)

500 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
3	10	3,000	$\frac{5}{6}$	1	120	12,000
5	10	5,000	$1\frac{7}{18}$	1	72	7,200
10	10	10,000	$2\frac{7}{9}$	1	36	3,600
15	10	15,000	$4\frac{1}{6}$	1	24	2,400
25	100	20,000	$5\frac{5}{9}$	1	180	18,000
50	100	50,000	$13\frac{8}{9}$	1	72	7,200
75	100	80,000	$22\frac{2}{9}$	1	45	4,500
100	100	100,000	$27\frac{7}{9}$	1	36	3,600
150	100	150,000	$41\frac{2}{3}$	1	24	2,400
200	1,000	200,000	$55\frac{5}{9}$	1	180	18,000
300	1,000	300,000	$83\frac{1}{3}$	1	120	12,000

100-200 Volts, 3-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
$2\frac{1}{2}$	10	1,000	$\frac{5}{18}$	1	360	36,000
5	10	2,000	$\frac{5}{9}$	1	180	18,000
$7\frac{1}{2}$	10	4,000	$1\frac{1}{9}$	1	90	9,000
10	10	4,000	$1\frac{1}{9}$	1	90	9,000
15	10	6,000	$1\frac{2}{3}$	1	60	6,000
25	10	10,000	$2\frac{7}{9}$	1	36	3,600
50	100	20,000	$5\frac{5}{9}$	1	180	18,000
75	100	30,000	$8\frac{1}{3}$	1	120	12,000
100	100	40,000	$11\frac{1}{9}$	1	90	9,000
150	100	60,000	$16\frac{2}{3}$	1	60	6,000
200	100	80,000	$22\frac{2}{9}$	1	45	4,500
300	100	120,000	$33\frac{1}{3}$	1	30	3,000

COLUMBIA TYPE SH CONTINUOUS CURRENT WATT-HOUR METERS

100 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
100	100	20,000	$5\frac{5}{9}$	1	180	18,000
150	100	30,000	$8\frac{1}{3}$	1	120	12,000
200	100	40,000	$11\frac{1}{9}$	1	90	9,000
300	100	60,000	$16\frac{2}{3}$	1	60	6,000
400	100	80,000	$22\frac{2}{9}$	1	45	4,500
500	100	100,000	$27\frac{7}{9}$	1	36	3,600
600	100	120,000	$33\frac{1}{3}$	1	30	3,000
800	100	150,000	$41\frac{2}{3}$	1	24	2,400
1,000	1,000	200,000	$55\frac{5}{9}$	1	180	18,000
1,200	1,000	200,000	$55\frac{5}{9}$	1	180	18,000

200 Volts, 2-Wire

100	100	40,000	$11\frac{1}{9}$	1	90	9,000
150	100	60,000	$16\frac{2}{3}$	1	60	6,000
200	100	80,000	$22\frac{2}{9}$	1	45	4,500
300	100	120,000	$33\frac{1}{3}$	1	30	3,000
400	100	150,000	$41\frac{2}{3}$	1	24	2,400
500	1,000	200,000	$55\frac{5}{9}$	1	180	18,000
600	1,000	200,000	$55\frac{5}{9}$	1	180	18,000
800	1,000	300,000	$83\frac{1}{3}$	1	120	12,000
1,000	1,000	400,000	$111\frac{1}{9}$	1	90	9,000
1,200	1,000	500,000	$138\frac{8}{9}$	1	72	7,200

COLUMBIA TYPE SH CONTINUOUS CURRENT WATT-HOUR METERS (*Continued*)

500 Volts, 2-Wire

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
100	100	100,000	$27\frac{7}{9}$	1	36	3,600
150	100	150,000	$41\frac{2}{3}$	1	24	2,400
200	1,000	200,000	$55\frac{5}{9}$	1	180	18,000
300	1,000	300,000	$83\frac{1}{3}$	1	120	12,000
400	1,000	400,000	$111\frac{1}{9}$	1	90	9,000
500	1,000	500,000	$138\frac{8}{9}$	1	72	7,200
600	1,000	600,000	$166\frac{2}{3}$	1	60	6,000
800	1,000	800,000	$222\frac{2}{9}$	1	45	4,500
1,000	1,000	1,000,000	$277\frac{7}{9}$	1	36	3,600
1,200	1,000	1,200,000	$333\frac{1}{3}$	1	30	3,000

100-200 Volts, 3-Wire

100	100	40,000	$11\frac{1}{9}$	1	90	9,000
150	100	60,000	$16\frac{2}{3}$	1	60	6,000
200	100	80,000	$22\frac{2}{9}$	1	45	4,500
300	100	120,000	$33\frac{1}{3}$	1	30	3,000
400	100	150,000	$41\frac{2}{3}$	1	24	2,400
500	1,000	200,000	$55\frac{5}{9}$	1	180	18,000
600	1,000	200,000	$55\frac{5}{9}$	1	180	18,000
800	1,000	300,000	$83\frac{1}{3}$	1	120	12,000
1,000	1,000	400,000	$111\frac{1}{9}$	1	90	9,000
1,200	1,000	500,000	$138\frac{8}{9}$	1	72	7,200

COLUMBIA TYPE C-1 WATT-HOUR METERS

100 Volts, 2-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
5	10	1,000	$\frac{5}{18}$	1	360	36,000
10	10	2,000	$\frac{5}{9}$	1	180	18,000
15	10	3,000	$\frac{5}{6}$	1	120	12,000
25	10	5,000	$1\frac{7}{18}$	1	72	7,200
50	10	10,000	$2\frac{7}{9}$	1	36	3,600
75	10	15,000	$4\frac{1}{6}$	1	24	2,400
100	100	20,000	$5\frac{5}{9}$	1	180	18,000
150	100	30,000	$8\frac{1}{3}$	1	120	12,000
200	100	40,000	$1\frac{1}{9}$	1	90	9,000
300	100	60,000	$16\frac{2}{3}$	1	60	6,000

200 Volts, 2-Wire, Single-Phase

$2\frac{1}{2}$	10	1,000	$\frac{5}{18}$	1	360	36,000
5	10	2,000	$\frac{5}{9}$	1	180	18,000
10	10	4,000	$1\frac{1}{9}$	1	90	9,000
15	10	6,000	$1\frac{2}{3}$	1	60	6,000
25	10	10,000	$2\frac{7}{9}$	1	36	3,600
50	100	20,000	$5\frac{5}{9}$	1	180	18,000
75	100	30,000	$8\frac{1}{3}$	1	120	12,000
100	100	40,000	$11\frac{1}{9}$	1	90	9,000
150	100	60,000	$16\frac{2}{3}$	1	60	6,000
200	100	80,000	$22\frac{2}{9}$	1	45	4,500
300	100	120,000	$33\frac{1}{3}$	1	30	3,000

COLUMBIA TYPE C-1 WATT-HOUR METERS (*Continued*)

100-200 Volts, 3-Wire, Single-Phase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
$2\frac{1}{2}$	10	1,000	$\frac{5}{18}$	1	360	36,000
5	10	2,000	$\frac{5}{9}$	1	180	18,000
10	10	4,000	$1\frac{1}{9}$	1	90	9,000
15	10	6,000	$1\frac{2}{3}$	1	60	6,000
25	10	10,000	$2\frac{7}{9}$	1	36	3,600
50	100	20,000	$5\frac{5}{9}$	1	180	18,000
75	100	30,000	$8\frac{1}{3}$	1	120	12,000
100	100	40,000	$11\frac{1}{9}$	1	90	9,000
150	100	60,000	$16\frac{2}{3}$	1	60	6,000
200	100	80,000	$22\frac{2}{9}$	1	45	4,500
300	100	120,000	$33\frac{1}{3}$	1	30	3,000

COLUMBIA TYPE C-3 WATT-HOUR METERS

100 Volts, Polyphase

$2\frac{1}{2}$	10	1,000	$\frac{5}{18}$	1	360	36,000
5	10	2,000	$\frac{5}{9}$	1	180	18,000
10	10	4,000	$1\frac{1}{9}$	1	90	9,000
15	10	6,000	$1\frac{2}{3}$	1	60	6,000
25	10	10,000	$2\frac{7}{9}$	1	36	3,600
50	100	20,000	$5\frac{5}{9}$	1	180	18,000
75	100	30,000	$8\frac{1}{3}$	1	120	12,000
100	100	40,000	$11\frac{1}{9}$	1	90	9,000
150	100	60,000	$16\frac{2}{3}$	1	60	6,000

COLUMBIA TYPE C-3 WATT-HOUR METERS
(Continued)

200 Volts, Polyphase

Capacity in Amperes	Numerical Value of 1 Revolution of 1st Dial Hand	Test Constant (K_t) (Watt-seconds)	Watt-hour Constant (K_h)	Numerical Value of Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
2½	10	2,000	5/9	1	180	18,000
5	10	4,000	1 1/9	1	90	9,000
10	10	8,000	2 2/9	1	45	4,500
15	10	12,000	3 1/3	1	30	3,000
25	100	20,000	5 5/9	1	180	18,000
50	100	40,000	11 1/9	1	90	9,000
75	100	60,000	16 2/3	1	60	6,000
100	100	80,000	22 2/9	1	45	4,500
150	100	120,000	33 1/3	1	30	3,000

500 Volts, Polyphase

3	10	6,000	1 2/3	1	60	6,000
5	10	10,000	2 7/9	1	36	3,600
10	100	20,000	5 5/9	1	180	18,000
15	100	30,000	8 1/3	1	120	12,000
25	100	50,000	13 8/9	1	72	7,200
50	100	100,000	27 7/9	1	36	3,600
75	100	150,000	41 2/3	1	24	2,400
100	1,000	200,000	55 5/9	1	180	18,000
150	1,000	300,000	83 1/3	1	120	12,000

(2) **The watt-hour constant,** standard symbol K_h, is the value of the electrical energy expressed in watt-hours required to be passed through the meter in order to cause the moving element to make one revolution.

The watt-hour constant has a definite value for each type and capacity of watt-hour meter, and is found by substituting the value of the test constant of the watt-hour meter in the following formulas.

The value of the test constant is in most cases marked on the watt-hour meter and should in all cases where possible be obtained from it, thus obviating the necessity of referring to a printed table.

Formulas for finding the watt-hour constant of various makes of watt-hour meters are given below:

General Electric Company:

Watt-hour constant = Test constant.

Westinghouse Electric & Manufacturing Company:

$$\text{Watt-hour constant} = \frac{\text{Test constant}}{3{,}600}. \quad \text{(For all Types except CW-6.)}$$

Watt-hour constant = Test constant. (For Type CW-6.)

Fort Wayne Electric Works:

For Type K watt-hour meters

$$\text{Watt-hour constant} = \frac{\text{Test constant}}{36}$$

For Types K1, K2, K3 and K4 watt-hour meters

Watt-hour constant = Test constant.

Sangamo Electric Company:

$$\text{Watt-hour constant} = \frac{\text{Test constant}}{3{,}600}$$

Duncan Electric Manufacturing Company:

Watt-hour constant = Test constant.

Columbia Electric Company:

$$\text{Watt-hour constant} = \frac{\text{Test constant}}{3{,}600}$$

The following example will illustrate the use of the above formulas:

EXAMPLE: Required to find the watt-hour constant of a Westinghouse Type B, two-wire, 5 ampere, 100 volt, single-phase meter.

SOLUTION: Referring to the table of test constants of Westinghouse Type B, single-phase watt-hour meters, we find for a 100 volt, two-wire, 5 ampere meter

Test constant = 1,200 watt-seconds.

Referring to the formulas for finding the watt-hour constant when the test constant is known, we find for Westinghouse watt-hour meters

$$\text{Watt-hour constant} = \frac{\text{Test constant}}{3{,}600.}$$

Substituting the value of the test constant (1,200) in this formula, we have

$$\text{Watt-hour constant} = \frac{1{,}200}{3{,}600} = \tfrac{1}{3} \text{ watt-hours}$$

Therefore the watt-hour constant of the given watt-hour meter is $\frac{1}{3}$ watt-hours.

(3) **The watt-second constant,** standard symbol K_s, is the value of the electrical energy expressed in watt-seconds required to be passed through the meter in order to cause the moving element to make one revolution.

The watt-second constant is equal to the watt-hour constant multiplied by 3,600, the number of seconds in one hour.

It can be found for any particular watt-hour meter by substituting the value of the test constant in the following formulas:

Formulas for finding the watt-second constants of various makes of meters are given below:

General Electric Company:

Watt-second constant = 3,600 × test constant.

Westinghouse Electric and Manufacturing Company:

Watt-second constant = Test constant. (For all Types except CW-6.)

Watt-second constant = 3,600 × Test constant. (For Type CW-6.)

Fort Wayne Electric Works:

For Type K watt-hour meters

Watt-second constant = 100 × test constant.

For Types K1, K2, K3 and K4 watt-hour meters

Watt-second constant = 3,600 × test constant.

Sangamo Electric Company:

Watt-second constant = Test constant.

Duncan Electric Manufacturing Company:

Watt-second constant = 3,600 × test constant.

Columbia Electric Company:

Watt-second constant = Test constant.

The following example will illustrate the use of the above formulas:

EXAMPLE: Required to find the watt-second constant of a Sangamo Type H, 10 ampere, 110 volt, two-wire, single-phase, watt-hour meter.

SOLUTION: Referring to the table of test constants for Sangamo Type H watt-hour meters, we find for a 110 volt, two-wire, 10 ampere watt-hour meter

Test constant = 1,500 watt-seconds.

Referring to the formula for finding the watt-second constant of a Sangamo watt-hour meter, when the test constant is given, we find

Watt-second constant = Test constant.

Therefore, the watt-second constant of the given meter is 1,500 watt-seconds.

(4) **The register constant,** standard symbol K_r, is the factor used in conjunction with the register reading in order to ascertain the total amount of electrical energy, in the desired unit that has passed through the meter.

In order to eliminate any chance of error, the method of obtaining the registration of a meter should be as simple as possible.

Since the registration is obtained by taking the product of the register reading and the register constant, it is obvious that the numerical values of these quantities should be such that would make the operation of obtaining their product a simple one.

Since the operation of multiplication occurs in its most simple form, when one of the factors is unity, it is therefore desirable that the numerical value of the register constant be unity throughout as wide a range of meter capacity as possible.

Experience in designing watt-hour meters has demonstrated that in order to minimize the wear on the jewel and other parts of the meter, and thereby promote the life of those parts, the speed of the moving element should not be more than 50 revolutions per minute. For this reason, the moving elements of all capacities of meters of a given type are caused to revolve at practically the same full load speed, and therefore the watt-hour constants necessarily increase as the capacity.

The quantities which enter into the formula for finding the register constant of a meter are the watt-hour constant, the gear ratio and the numerical value of one revolution of the first dial hand.

Since the value of the watt-hour constant varies as the capacity, it is therefore governed by the capacity of the meter, hence the gear ratio and the numerical value of one revolution of the first dial hand are the only remaining quantities which can be varied in order that the numerical

value of the register constant may be kept the same for meters of different capacities.

In the design and construction of the registering mechanisms of meters the manufacturers have kept the numerical value of the register constant unity for meters of ordinary capacity, by assigning the proper values to the divisions of the dials and giving the gear ratios such values that are consistent with efficient mechanical operation.

For high capacity meters, the values necessary to be assigned to the divisions of the dials became too large and those to the gear ratios too small, in order that the numerical value of the register constant be unity; for such meters the numerical value of the register constant is increased to 10, 100 or 1,000, as may be necessary.

The relation between the register constant, watt-hour constant, gear ratio and the numerical value of one revolution of the first dial hand is given by the following formulas.

To find the register constant of a watt-hour meter when it is desired that the registration be expressed in kilowatt-hours, use the following formula:

$$\text{Register constant} = \frac{\text{Watt-hour constant} \times \text{gear ratio}}{1{,}000 \times N}$$

in which

$N =$ the numerical value of one revolution of the first dial hand.

To find the register constant of a watt-hour meter when it is desired that the registration be expressed in watt-hours, use the following formula:

$$\text{Register constant} = \frac{\text{Watt-hour constant} \times \text{gear ratio}}{N'}$$

in which

$N' =$ the numerical value of one revolution of the first dial hand.

In Thomson (General Electric) Type M, Form J-2 and D-2 meters, the number marked on the meter is not the register ratio but a fraction of a revolution of the first dial hand for ten revolutions of the wormwheel. For these meters,

$$\text{Register constant} = \frac{\text{Watt-hour constant} \times 1{,}000}{\text{Number marked on meter} \times N'}$$

An explanation of the methods employed in **deducing the formulas for finding register constants** follows:

Consider as an example a meter whose registration is desired in kilowatt-hours.

Let N = the numerical value of one revolution of the first dial hand, then

$$\text{(1)}\quad \left.\begin{array}{l}\text{Registration in kilowatt-hours correspond-}\\\text{ing to 1 revolution of the first dial hand}\end{array}\right\} = \text{N} \times \text{register constant.}$$

The amount of electrical energy, expressed in kilowatt-hours required to be passed through the meter in order to cause the hand of the first dial to make one revolution, is expressed by the formula:

$$\text{(2)}\quad \left.\begin{array}{l}\text{Kilowatt-hours through meter}\\\text{required to cause hand of first}\\\text{dial to make one revolution}\end{array}\right\} = \frac{\text{Watt-hour constant} \times \text{gear ratio}}{1{,}000}$$

The meter being correct, the registration for a given period of time will correspond to the amount of electrical energy that has passed through the meter during that period.

Therefore:

The first member of equation (No. 1) is equal to the last member of equation (No. 2), or

$$\text{(3)}\quad \left.\begin{array}{l}\text{Registration in kilowatt-hours}\\\text{corresponding to 1 revolution}\\\text{of the first dial hand}\end{array}\right\} = \frac{\text{Watt-hour constant} \times \text{gear ratio}}{1{,}000}$$

Since the first members of equations (No. 1) and (No. 3) are identical, the last members of these equations are equal, and

$$\text{(4)}\qquad \text{N} \times \text{register constant} = \frac{\text{Watt-hour constant} \times \text{gear ratio}}{1{,}000}$$

Therefore, for a meter whose registration is desired in kilowatt-hours

$$\text{(5)}\qquad \text{Register constant} = \frac{\text{Watt-hour constant} \times \text{gear ratio}}{1{,}000 \times \text{N}}$$

If it is desired to find the register constant of a meter whose registration is to be expressed in watt-hours, the factor 1,000 is not used and formula (No. 5) becomes

$$\text{(6)}\qquad \text{Register constant} = \frac{\text{Watt-hour constant} \times \text{gear ratio}}{\text{N}'}$$

in which

N′ = the numerical value of one revolution of the first dial hand.

In Thomson (General Electric) Type M, Form J-2 and D-2 meters, the number marked on the meter is not the register ratio, but a fraction of a revolution of the first dial hand for ten revolutions of the worm-wheel.

For these meters,

$$\text{(7)} \qquad \text{Gear ratio} = \frac{1{,}000}{\text{Number marked on meter}}$$

Substituting in formula (No. 6) for gear ratio, its equivalent as given by formula (No. 7),

$$\text{(8)} \qquad \text{Register constant} = \frac{\text{Watt-hour constant} \times 1{,}000}{\text{Number marked on meter} \times N'}$$

In order to demonstrate the application of the formulas for finding the register constant of a meter the following **examples** are given:

Required to find the register constants of the following meters:

(1) Westinghouse, Type OA, 5 ampere, two-wire, 100 volt, single-phase meter, the registration to be expressed in kilowatt-hours.

SOLUTION: For this make, type and size of meter we find from the Westinghouse table,

Watt-hour constant $= \frac{1}{3}$ watt-hours.
Gear ratio $= 30{,}000$
Value of N $= 10$

By formula (No. 5)

$$\text{Register constant} = \frac{\frac{1}{3} \times 30{,}000}{1{,}000 \times 10} = 1 \text{ kilowatt-hour.}$$

(2) Thomson (General Electric) Type M, Form J-2, 50 ampere, two-wire, 110 volt meter, the registration to be expressed in watt-hours.

From the Thomson (General Electric) tables, we find for this type, form, size and style of meter,

Watt-hour constant $= 2$ watt-hours.
Number marked on meter $= 0.2$
Value of $N' = 1{,}000$

By formula (No. 8)

$$\text{Register constant} = \frac{2 \times 1{,}000}{0.2 \times 1{,}000} = 10 \text{ watt-hours.}$$

The register ratio, standard symbol R_r, is the number of revolutions required to be made by the wheel meshing with the worm or pinion on the moving element shaft to cause the first dial hand to make one revolution.

Several manufacturers mark the value of the register ratio on their meters. The following table shows on what part of the various makes of watt-hour meters it can be found.

Make of Meter	Location of Register Ratio on Meter
General Electric	On back plate of register.
Westinghouse	Marked on Type OA watt-hour meters only. On the back plate of the register.
Fort Wayne	Not marked on meters of earlier types. Marked on the back plate of the register of later type meters.
Sangamo	Not marked on meter. Found by multiplying the number marked on the back plate of the register by 200 for Type H watt-hour meters and by 100 for Types D and F watt-hour meters.
Duncan	Not marked on meter.
Columbia	On the back of the register.

The gear ratio, standard symbol R_g, is the number of revolutions required to be made by the moving element to cause the first dial hand to make one revolution.

If the register ratio of a meter is known, the gear ratio can be found by multiplying the register ratio by the ratio of the reduction from the moving element shaft to the gear meshing with it.

For meters having a single pitch worm on the watt-hour meter shaft meshing with a worm-wheel of 100 teeth, the formula is

$$\text{Gear ratio} = \text{Register ratio} \times 100.$$

For watt-hour meters in which a pinion is used on the meter shaft, meshing with a wheel of the register, the formula is

$$\text{Gear ratio} = \text{Register ratio} \times \frac{\text{Number of teeth in gear}}{\text{Number of teeth in pinion}}$$

In the General Electric Type M, Form J-2 and D-2 meters the worm-eel has 100 teeth. and instead of the number that is marked on the

meter being the register ratio (as defined by definition) it is the fraction of a revolution of the first dial hand for 10 revolutions of the worm-wheel.

For those meters

$$\text{Gear ratio} = \frac{1{,}000}{\text{Number marked on meter}}$$

The gear ratio can be found by substituting the value of the register ratio in the following formulas:

General Electric Company:

$$\text{Gear ratio} = 100 \times \text{register ratio.}$$

Westinghouse Electric and Manufacturing Company:

For Round Type and Type A watt-hour meters,

$$\text{Gear ratio} = 10 \times \text{register ratio.}$$

For Types B, B prepayment, C single-phase watt-hour meters, and Type DC (plain meters) continuous current watt-hour meters,

$$\text{Gear Ratio} = 6\tfrac{1}{4} \times \text{Register Ratio.}$$

For Type C polyphase watt-hour meters, and Type DC (Sub A. meters) continuous current watt-hour meters,

$$\text{Gear Ratio} = 5 \times \text{Register Ratio.}$$

For Type OA watt-hour meters,

$$\text{Gear Ratio} = 12\tfrac{1}{2} \times \text{Register Ratio.}$$

For Type CW-6 continuous current watt-hour meters,

$$\text{Gear Ratio} = 100 \times \text{Register Ratio.}$$

Fort Wayne Electric Works:

$$\text{Gear ratio} = 100 \times \text{register ratio.}$$

Sangamo Electric Company:

For Types D and F watt-hour meters

$$\text{Gear ratio} = 5{,}000 \times \text{number on back of register.}$$

For Type H watt-hour meters

$$\text{Gear ratio} = 10{,}000 \times \text{number on back of register.}$$

Duncan Electric Manufacturing Company:

$$\text{Gear ratio} = 100 \times \text{register ratio.}$$

Columbia Electric Company:

$$\text{Gear ratio} = 100 \times \text{register ratio.}$$

CHAPTER XVI

DESCRIPTIVE DATA ON VARIOUS TYPES OF WATT-HOUR METERS

THE DESCRIPTIVE MATERIAL AND DATA IN THIS CHAPTER HAVE BEEN KINDLY FURNISHED BY THE MANUFACTURERS, AND ARE GIVEN ON THEIR AUTHORITY AND NOT ON THAT OF THE COMMITTEE ON METERS

CHAPTER XVI

Descriptive Data on Various Types of Watt-hour Meters

THOMSON (GENERAL ELECTRIC) CONTINUOUS CURRENT WATT-HOUR METERS

The **Thomson (General Electric) continuous current, watt-hour meter** in its simplest form embodies three necessary elements, namely, a motor causing rotation, a generator providing the necessary load or drag, and a registering device, the function of which is to integrate the instantaneous values of the electrical energy passing in the system to be measured, as explained in Chapter III. (Fig. 404.)

The first "Thomson Recording Wattmeters" were designated as the Form J, the Form F, and the Form D.

The Form F meter was replaced by the Form D, so as to make all capacities from 25 to 600 amperes of the same dimensions.

Forms J-1 and D-1 meters were dust-proof and supplied with an adjustable shunt field coil, thus providing for necessary light-load adjustment at the time and place of installation.

Still later modifications resulted in discarding the old form of non-direct reading register requiring the use of register constants other than unity, and in the substitution of a direct reading register.

The holder for the adjustable shunt coil was simplified so that it could be used on meters of from 3 to 600 amperes capacity.

The electrical qualities were improved and with these new features added, the meters became known as the Forms J-2 and D-2. (Figs. 405 to 407.)

For measuring the total output on continuous current switchboards, meters were designed ranging in capacity from 800 to 10,000 amperes. These are provided with two adjustable shunt field coils.

Form G-2 meters were those of high capacity, switchboard type, and were superseded by Form GG-4 (Fig. 408).

A word of explanation may not be amiss in regard to the **significance of form letters** used in connection with Thomson recording wattmeters prior to 1904.

CC

FIG 404.—Diagram of Thomson Recording Watt-hour Meter A, Armature; BB', Brushes, C, Commutator; CC, Friction Compensation Coil, D, Disk; MM', Drag Magnets, R, Resistance, S, Shaft; SFC, SFC', Series Field Coils, T, Terminals; W, Worm; WW', Worm Wheel.

FIG. 405.—Thomson Recording, Form J-2, Watt-hour Meter and Cover.

FIG. 406.—Annotated View of Thomson Recording, Form J-2, Watt-hour Meter

J—Standard meter for currents of 3 to 15 amperes inclusive, low efficiency.

D—Standard meter for currents of 15 to 600 amperes inclusive, low efficiency.

F—Old form superseded by "D."

E—Meter with extended base for cage resistance.

EE—Meter with extended base for resistance (1,200 amperes only).

E and EE—were superseded by the "D" forms.

N—Used with other letters to indicate high efficiency meters.

(G)—Used to indicate high capacity meter.

(C4)—Thomson single-phase service type induction meter, direct-reading register. Superseded by high torque, and now obsolete (Fig. 409).

Form J-2 meters are those of small capacity, ranging from 3 to 15 amperes, front connected and 3 to 10 amperes, back connected (Figs. 410 and 411).

Form D-2 includes meters of larger capacity than those mentioned; up to and including 1,200 amperes.

In quality and construction Forms J-2 and D-2 are identical, differing only in general dimensions, and in the fact that J-2 meters have 2 magnets and D-2 meters have 3 magnets.

The **standard finish** of the "Thomson Recording Wattmeters" for secondary circuits, up to and including 600 amperes capacity, is a sheet metal cover, finished in black japan, with no glass except in front of dials. Special finish and glass covers were furnished when desired.

The **registers** on all Thomson watt-hour meters manufactured previous to Forms J-2 and D-2, high torque and polyphase meter, manufactured previous to serial number 475,602, were equipped with non-direct reading registers, i. e., the register readings have to be multiplied by a register constant marked on the dial face in order to obtain the correct number of watt-hours registered (Fig. 413).

With the use of the direct reading registers, meters are direct reading, or require only the use of constant 10, or a multiple of it (Fig. 414).

The **full load adjustment** of speed is obtained by moving the drag magnets in such a way as to vary the radius at which the retarding force acts upon the metal disk, rotated between their poles by the meter armature.

These watt-hour meters are provided with an adjustable **light load compensation,** by means of which the light load accuracy may be corrected without materially affecting the operation of the meter at any other load.

Under no circumstances should the light load accuracy of a commutating watt-hour meter be controlled by altering the friction compo-

FIG. 407.—Thomson Recording, Form D-2, Watt-hour Meter.

FIG. 408.—Thomson Recording, Astatic Type, Form GG-4 Watt-hour Meter.

FIG. 409.—Thomson, Single-phase, Form G-4 Induction Meter.

FIG. 410.—Prepayment Mechanism.

nent of the brushes and commutator, as the brush adjustment once made for a certain location should not be altered.

After the watt-hour meter has been in service for a couple of months it will show a tendency to run slow on light loads, due to the tarnished

condition of the commutator. It should then be corrected, not by cleaning the commutator or brushes, which are now in their normal and constant condition, but by moving the adjustable shunt nearer the armature.

FIG 411—Thomson Recording, Form J-2 Watt-hour Meter with Prepayment Device.

FIG 412—Thomson Recording, Street-Car Type Watt-hour Meter

After this correction, further deterioration at the commutator is not to be anticipated.

A distinction must be made between a tarnished commutator, which is constant and does not spark, and a rough commutator which has been caused by sparking and which continues to spark and is not in a con-

stant condition. The former is constant and should not be altered; the latter should be smoothed up by tape but not brightened, and the brushes readjusted to give sparkless operation, after which the necessity of further change is extremely improbable.

To place adjustable shunt field coils in older type Thomson watt-hour meters with stationary shunt field coils, remove the stationary coil and disconnect it from the circuit. In this operation care must be taken not to injure the insulation of either the field winding or the armature. Remove the resistance enclosed in an envelope inside of the meter or mounted in a resistance box. The resistance is wound in sections of iron and German silver wire or is composed entirely of copper. Part of this wire is to be removed. The iron wire may be detected by the use of a magnet passed over the coils. Remove all of the German silver wire from the resistance card, place the card in its new envelope, first completing the connections of the reduced resistance to its two terminal wires and reinsert the resistance card into the meter, but do not seal the envelope. If the resistance is wound on tubes, they should be taken from the box and a part of the wire removed, after which the connections must be made as noted above.

FIG. 413.—Non-direct Reading Register.

FIG. 414.—Direct Reading Register.

After connections have been made, the watt-hour meter should be tested to prove the accuracy of the work. If improperly connected, the meter will run slower, on light loads when the coil is in place, instead of faster. A reversal of the leads will correct the error.

The watt-hour meter should now be tested on full load. If it runs within 5 per cent of normal with the magnets in their original position, sufficient wire has been removed. If the meter runs more than 5 per cent slow, remove still more of the wire from the resistance. The whole purpose is to bring the total resistance of the armature circuit to approximately its original value. Having done this, make the electrical

connections permanent, and if an internal resistance, seal the envelope. Great care must be exercised to make good electrical joints in the connections. Only resin, dissolved in alcohol, should be used in soldering.

Commutator type watt-hour meters which have a tendency to creep may be corrected by fastening a small U-shaped piece of iron on the edge of the disk of the moving element (Chapter VII, page 393). This will exert a momentary restraining force when it is opposite one of the magnets and is sufficient to prevent creeping on potential alone. Such a device is readily constructed by closing a small piece of approximately 0.035 inch (diameter) iron wire on itself and slipping it over the edge of the disk.

Adjustment of the effect may be made by sliding the wire to and from the edge of the disk, thus approaching, or receding from, the magnet pole. The U-shaped iron should be as near the edge of the disk as possible, consistent with no rotation on potential alone.

The adjustment of the U-shaped iron should be made with great care, as a sluggish action of the disk will lower the accuracy of the watt-hour meter on light loads. After making a sensitive adjustment sufficient to prevent creeping, the watt-hour meter can be adjusted for light load accuracy by moving the adjustable shunt. Many methods used heretofore to prevent creeping have affected the light load accuracy, but by the use of the U-shaped iron, as described above, this feature is entirely eliminated.

The U-shaped iron must never be used on watt-hour meters of the induction type, owing to the fact that it would give trouble at the light load adjustment.

Commutators and brushes when shipped from the factory are untarnished and carefully adjusted. The first care should be to inspect the adjustment of the brushes to see that it is not altered in transportation. The brushes should rest evenly and uniformly on the commutator and both fingers have the same tension. If this tension is too light, sparking is liable to occur, particularly if the watt-hour meter is installed in a location subject to considerable vibration; if too heavy, it introduces excessive friction errors and causes underregistration on light loads. Either extreme condition is liable to roughen up the commutator and should be avoided.

The tension may be estimated by carefully pressing back the brush about three-eighths inch from the commutator and, when released, noting that it does not rebound after striking.

Another method is to press back one-half of the brush and note that the second half leaves the commutator when the first has traveled about one-eighth inch.

The brush tension should be made suitable for the point of installation and not changed. The light load accuracy should not be obtained by means of brush adjustment but by following instructions, given above, covering light load adjustments.

No lubricant of any kind should be used on the commutator, as it is liable to get between the segments and cause variable speed and unsatisfactory operation.

"Thomson Recording Wattmeters" of the commutator type in capacities less than 50 kilowatts are furnished with **sapphire jewels,** and those of larger capacity with **diamond jewels** in place of sapphire jewels.

Pivots are made of steel piano wire, which is drawn under enormous pressure. These wires are hardened glass hard and highly polished; still, when they have been operating for any length of time upon a broken, or rough, jewel, this highly polished surface is broken, probably charged with small particles of sapphire or diamond, and the pivot becomes a cutting tool. For this reason, a new pivot should always be inserted when the jewel has been replaced.

Before inserting the new jewel it is well to place a small drop of fine watch oil in the cup.

When inserting a new jewel, it may be found necessary to raise, or lower, the moving element of the meter. To do this, insert the jewel screw and turn until it clamps tightly against the bushing. Loosen the hexagonal brass check-nut under the watt-hour meter disk. The desired adjustment can then be made by turning the jewel screw up or down, the bushing referred to moving with it. When the proper point has been reached, the check-nut must be carefully tightened. On some types of these meters the check-nut is located beneath the meter base, as shown in Fig. 415.

To insert a new pivot, loosen the jewel screw until the disk rests upon the magnets where it should be firmly wedged. Then remove the jewel screw entirely from the meter and insert the pivot wrench in its place. Press firmly, thus clamping the pivot in the end of the wrench and unscrew. Replace the pivot by a new one and screw into the shaft. Remove the wedges from the disk and insert the jewel screw.

Care must be exercised in this operation that the adjustment of the brushes of the watt-hour meter is not altered and that neither the shaft nor disk is sprung.

To obain the best jewel life it necessitates construction having a spring strength suitable to the weight under which it is to operate. Owing to the decrease in the weight of the moving element of the later forms of

from that used in meters having copper disks should be inserted. As the weight of the moving element varies in the different types of meters, jewels are furnished for each type. There are four classes of jewels for use with the following watt-hour meters.

"Single" disk aluminum, "Single" disk copper, "Double" disk aluminum and "Double" disk copper. All sapphire jewels, with the

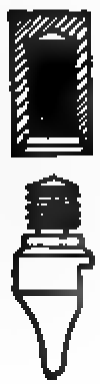


FIG. 415—Cross Section of Bearing of Thomson Recording Watt-hour Meters.

exception of a Catalog No. 6704, are mounted in fillister head screws, the diamond jewels having hexagonal heads. Jewels of different spring strengths are classified by finishes as given below:

For meters	with	"Single"	aluminum	disk	....	Nickel
"	"	"	copper	"	....	Brass
"	"	"Double"	aluminum	"	....	Oxide
"	"	"	copper	"	....	Copper

Armatures for Thomson watt-hour meters of these types from 3 to 1,200 amperes capacity are wound on one standard size of core.

To place a new armature in a meter, it is necessary to remove the brush at the bracket, the field coils and the magnets; also to remove the disk from the shaft. The armature is held in place by set screws inside of the winding. These may be loosened by inserting a small screw driver.

The ends of the commutator segments must be cleaned and the leads of the new armature carefully soldered in place, using resin dissolved in alcohol as flux.

Special care must be taken that none of the solder runs down between the segments.

After soldering in place, the armature should be allowed to hang by its own weight (suspended by its leads) from the commutator. The leads will then be straight, or, in other words, parallel with the meter shaft.

If the armature has eight coils, it will be found that every alternate tooth projecting between the coils is exactly opposite the space between the commutator segments. Choosing one of these alternate teeth and calling it No. 1, count to the right six teeth. The sixth tooth will be found to be exactly opposite a commutator segment. Holding the shaft, the armature should be revolved upon it until tooth No. 6 occupies the previous position of tooth No. 1.

If the armature has sixteen coils, it will be noticed that every alternate tooth that projects between the coils will be exactly opposite a commutator segment. Choosing one of these alternate teeth and calling it No. 1, count six teeth to the right as before. The sixth tooth will be found to be exactly opposite a commutator segment. The armature must then be revolved until tooth No. 6 occupies the previous position of tooth No. 1, thus giving the armature the same lead as before.

A few **general notes** on these older types of "Thomson Recording Wattmeters" will now be given.

Meters equipped with direct reading registers have a test constant which is used in testing only and must not be used in calculating consumers' bills.

This test constant will be found marked on the terminal boards, or watt-hour meter disk, and takes into consideration the reduction in the gear train to the dial hand of first dial of the register.

In the older types of watt-hour meter which were not equipped with direct reading registers, the test constant and that marked on the dial face—register constant—were identical.

In case it becomes necessary to bring the leads from the line, or generator, to the right-hand binding post, in place of the left-hand binding post, the meter will run in reverse direction. This may be corrected by connecting the brush resistance lead to the opposite connection clip and reversing the position of the shunt field leads. To reverse these connections, the lead connected to the binding post should be attached to the remaining brush connection clip, and the lead originally connected to the brush connection clip should be secured to the binding post.

This method of connection should always be followed in preference to reversing the entire potential circuit at the binding post, otherwise, full

difference of potential will be placed between the field and adjustable shunt coil.

Oil should never be used in the top bearing of a commutating watt-hour meter, as it is liable to run down and get between the commutator segments. If the registering mechanism is oiled it must be carefully wiped afterward, so that no oil may drop from it.

The following **instructions for installing** these types of watt-hour meters are given by the manufacturer.

Screw the meter to a solid perpendicular support, inserting the screw through the upper right-hand hole, then one through the diagonally opposite hole.

Bring the meter very carefully to a level, using a small spirit level on the base near the magnets. Then insert screws in the two remaining holes and fasten the meter firmly to the wall.

Connect the meter in circuit according to the diagram of its class. (See illustrations and notice on the back of the meter.)

In those meters which have no rubber diaphragm to close the holes around the wires entering the meter, it is desirable to fill any space around these wires with tissue paper or some other substance to prevent the entrance of dust, being extremely careful that it does not project on the inside in such a manner as to touch the disk.

If the jewel is removable, insert the jewel screw in the base of the meter, turning it in to the full length of the screw.

If the jewel is fixed, remove the wedge from under the nut beneath the disk which raises the shaft of the jewel and screw the nut down on the lower check nut, thus gently lowering the shaft into its jeweled bearing.

Adjust the top bearing stud until the end of the stud is halfway between the shoulder and the end of the shaft; fix at this point by means of the set screw provided for the purpose.

The meter may now be started. Never allow the shaft to rest on the jewel until everything else is ready for the meter to be started.

The meter must never be moved with the shaft resting on the jewel.

Be cautious about changing the tension of the brushes, as they are carefully adjusted before leaving the factory.

A slight sparking will sometimes be noticed at the commutator when the meter is first started. This will soon disappear, as it is due to small particles of dust which have collected on the commutator and brushes in shipment and which will soon wear off.

Should the commutator need cleaning, carefully insert a piece of narrow tape between it and the brushes. Draw the tape gently back and forth, at the same time slowly rotating the shaft.

Be careful in doing this not to spring the brushes out of their original position.

See that the disk and armature move freely, and that no dirt collects on the magnets in such a way as to touch the disk.

Install the meter in a dry place as far away from any heavy vibration as possible.

When it is necessary to install a meter near a railroad or in any place where the vibration is sufficient to cause sparking at the brushes, the tension of the brushes, upon the commutator, should be slightly increased. This will do away with the sparking and ensure greater accuracy.

In case of severe jar it is of advantage to place a number of soft rubber washers under the heads of the screws which bind the meter to the wall and between the meter and the wall itself at each screw.

Testing formulas and constants for these meters will be found in Chapter XV, and testing methods in Chapter VII.

The watts recorded by the meter, i. e., the rate at which the meter is recording, can be found by the formula:

$$\frac{3600 \times K_h \times R}{S} = \text{watts.}$$

R = Number of revolutions of meter under test.
S = Number of seconds required to make this number of revolutions.

K_h = The test, or watt-hour, constant .... $\left\{\begin{array}{l}\text{Marked on dial plate of "Non-}\\\text{Direct" reading meters and}\\\text{on meter disk of "Direct"}\\\text{reading meters.}\end{array}\right.$

3,600 = Number of seconds in an hour.

The following **tables** give **detailed data** relative to these earlier types of "Thomson Recording Wattmeters." Table of Constants will be found in Chapter XV.

MATURE DATA FOR FORMS J, JN, J–1, J–2, FN, D, DN, D–1, D–2.

Volts	Amps.	Form	No. Coils	Turns	Wire	Label	Res.
50–55	3	J, J-1, J-2	8	260	.005 SCC	11	120
"	5	"	"	"	"	"	"
"	10	"	"	"	"	"	"
"	15	"	"	"	"	"	"
"	15	D, D-1, D-2	"	"	"	"	"
"	25	"	"	"	"	"	"
"	50	"	"	"	"	"	"
"	75	"	"	"	"	"	"
"	100	"	"	"	"	"	"
"	150	"	"	"	"	"	"
"	200	"	"	"	"	"	"
"	300	"	"	"	"	"	"
"	450	"	"	"	"	"	"
"	600	"	"	"	"	"	"
55	1200	"	"	"	"	"	"
100–110	3	JN, J1, J-2	8	1000	.003 SSC	4	1180
"	5	J-1	"	900	"	10	1050
"	5	J-2	"	1000	"	4	1180
"	10	J-1, J-2	"	"	"	"	"
"	15	"	"	"	"	"	"
"	15	DN, FN, D-1, D-2	"	"	"	"	"
"	25	"	"	"	"	"	"
"	50	"	"	"	"	"	"
"	75	"	"	"	"	"	"
"	100	"	"	"	"	"	"
"	150	"	"	"	"	"	"
"	200	"	"	"	"	"	"
"	300	"	"	"	"	"	"
"	450	"	"	"	"	"	"
"	600	"	"	"	"	"	"
110	1200	"	"	"	"	"	"
200–220	3	JN, J-1, J-2	16	500	.003 SSC	1	1180
"	5	"	"	"	"	"	"
"	10	"	"	"	"	"	"
"	15	"	"	"	"	"	"
"	15	DN, FN, D-1, D-2	"	"	"	"	"
"	25	"	"	"	"	"	"
"	50	"	"	"	"	"	"
"	75	"	"	"	"	"	"
"	100	"	"	"	"	"	"
"	150	"	"	"	"	"	"
"	200	"	"	"	"	"	"
"	300	"	"	"	"	"	"
"	450	"	"	"	"	"	"
"	600	"	"	"	"	"	"
220	1200	"	"	"	"	"	"

ARMATURE DATA FOR FORMS JEN, J-3, D-3, DEN, J-1, D-1, J-2, D-2 WATT-HOUR METERS

	Volts	Amps.	Form	No. Coils	Turns	Wire	Label	Res.
2-Wire	500–550	3	JEN, J-1, J-2	16	500	.003 SSC	1	1180
	"	5	"	"	"	"	"	"
	"	10	"	"	"	"	"	"
	"	15	"	"	"	"	"	"
	"	15	DEN, D-1, D-2	"	"	"	"	"
	"	25	"	"	"	"	"	"
	"	50	"	"	"	"	"	"
	"	75	"	"	"	"	"	"
	"	100	"	"	"	"	"	"
	"	150	"	"	"	"	"	"
	"	200	"	"	"	"	"	"
	"	300	"	"	"	"	"	"
	"	450	"	"	"	"	"	"
	"	600	"	"	"	"	"	"
	550	1200	"	"	"	"	"	"
3-Wire	200–220	3½	J3, J-1, J-2	8	1000	.003 SSC	4	1180
	"	7½	J-1	"	650	.004 SSC	2	425
	"	7½	J-2	"	1000	.003 SSC	4	1180
	"	10	J-1, J-2	"	"	"	"	"
	"	15	D3, J-1, J-2	"	"	"	"	"
	"	25	D3, D-1, D-2	"	"	"	"	"
	"	50	"	"	"	"	"	"
	"	75	"	"	"	"	"	"
	"	100	"	"	"	"	"	"
	"	150	"	"	"	"	"	"
	"	200	"	"	"	"	"	"
	"	300	"	"	"	"	"	"

ARMATURE DATA FOR HIGH CAPACITY G-2 CONTINUOUS CURRENT, ASTATIC WATT-HOUR METERS

Volts	Amps.	No. Coils	Turns per Coil	Wire	Label	Total Res.
110	2500	8	500	.005 SSC	12	480
"	4000	"	375	"	14	360
"	5000	"	"	"	"	"
"	6500	"	"	"	"	"
"	8000	"	"	"	"	"
"	10000	"	"	"	"	"
220	2500	"	750	.004 SSC	13	1100
"	4000	"	500	.005 SSC	12	480
"	5000	"	"	"	"	"
"	6500	"	"	"	"	"
"	8000	"	"	"	"	"
"	10000	"	"	"	"	"
550	2500	"	750	.004 SSC	13	1100
"	4000	"	500	.005 SSC	12	480
"	5000	"	"	"	"	"
"	6500	"	"	"	"	"
"	8000	"	"	"	"	"
"	10000	"	"	"	"	"

This data applies to each armature except the resistance which is the total for both.

ARMATURE DATA FOR PRIMARY WATT-HOUR METERS

HIGH EFFICIENCY

Volts	Amps.	Form	No. Coils	Turns per Coil	Wire	Label	Total Res.
1100-2200	10	J-1, J-2	8	1000	.003 SSC	4	1180
"	15	D-1, D-2	"	"	"	"	"
"	25	"	"	"	"	"	"
"	50	"	"	"	"	"	"
"	75	"	"	"	"	"	"
"	100	"	"	"	"	"	"
"	150	"	"	"	"	"	"
"	200	"	"	"	"	"	"
"	300	"	"	"	"	"	"
"	450	"	"	"	"	"	"
"	600	"	"	"	"	"	"

SHUNT FIELD COILS

STATIONARY				ADJUSTABLE				ADJUSTABLE			
J, JN, J-3, PN, DEN, EEN, D-3				J-1 and D-1				J-2 and D-2			
Turns	Wire	Res.	Form	Turns	SSC Wire	Res.	Form	Turns	SSC Wire	Res.	Form
								550	.005	150 ohms	J-2
				600	.005	150 ohms	J-1	"	"	"	"
150	*.007	25 ohms	J	"	"	"	"	"	"	"	"
"	"	"	"	550	"	137 ohms	"	"	"	"	"
"	"	"	F	500	"	125 ohms	D-1	"	"	"	D-2
"	"	"	"	"	"	"	"	"	"	"	"
"	"	"	"	"	"	"	"	"	"	"	"
"	"	"	"	"	"	"	"	"	"	"	"
"	"	"	"	"	"	"	"	"	"	"	"
200	"	33 ohms	DE	"	"	"	"	"	"	"	"
"	"	"	"	"	"	"	"	"	"	"	"
"	"	"	"	"	"	"	"	"	"	"	"
"	"	"	"	"	"	"	"	"	"	"	"
500	"	85 ohms	EE	650	"	162 ohms	"	"	"	300 ohms	"
				700	.004	280 ohms	J-1	800	.004	320 ohms	J-2
275	.005	75 ohms	JN	800	"	320 ohms	"	"	"	"	"
"	"	"	"	700	"	280 ohms	"	"	"	"	"
350	"	95 ohms	"	1000	"	400 ohms	"	"	"	"	"
"	**.005	"	FN	"	"	"	D-1	"	"	"	D-2
"	"	"	"	"	"	"	"	"	"	"	"
"	"	"	"	800	"	320 ohms	"	"	"	"	"
"	"	"	"	"	"	"	"	"	"	"	"
"	"	"	"	"	"	"	"	"	"	"	"
400	"	110 ohms	DEN	"	"	"	"	"	"	"	"
"	"	"	"	"	"	"	"	"	"	"	"

SHUNT FIELD COILS—Continued

	Stationary				Adjustabl				Adjustable			
	J, JN, J-3, FN, DEN, EEN, D-3				J-1 and D-1				J-2 and D-2			
2-Wire	Turns	Wire	Res	Form	Turns	SSC Wire	Res.	Form	Turns	SSC Wire	Res.	Form
10	400	**.005	110 ohms	DEN	800	.004	320 ohms	D-1	800	.004	320 ohms	D-2
	"	"	"	"	"	"	"	"	"	"	"	"
	600	"	160 ohms	EEN	"	"	"	"	"	"	640 ohms	"
20		*.005			1500	.003	980 ohms	J-1	1200	"	480 ohms	J-2
	300	"	80 ohms	JN	1200	.004	480 ohms	"	"	"	"	"
	"	"	"	"	1600	.003	1040 ohms	"	"	"	"	"
	500	"	135 ohms	"	1500	"	980 ohms	"	"	"	"	"
	"	"	"	FN	1200	.004	480 ohms	D-1	"	"	"	D-2
	"	"	"	"	"	"	"	"	"	"	"	"
	"	"	"	"	"	"	"	"	"	"	"	"
	"	"	"	"	"	"	"	"	"	"	"	"
	700	"	190 ohms	"	"	"	"	"	"	"	"	"
	"	"	"	DEN	"	"	"	"	"	"	"	"
	"	"	"	"	"	"	"	"	"	"	"	"
	"	"	"	"	"	"	"	"	"	"	"	"
	"	"	"	"	"	"	"	"	"	"	"	"
	800	*.004	320 ohms	EEN	950	"	380 ohms	"	1000	"	800 ohms	"
50	500	"	220 ohms	JEN	1500	.003	980 ohms	J-1	1200	"	480 ohms	J-2
	700	"	300 ohms		"	"	"	"	"	"	"	"
	"	"	"	"	"	"	"	"	"	"	"	"
	900	"	245 ohms	"	"	"	"	"	"	"	"	"
	"	"	"	EN	"	"	"	D-1	"	"	"	D-2
	"	"	"	"	"	"	"	"	"	"	"	"
	"	"	"	"	"	"	"	"	"	"	"	"

† 1200 amp. meters have two shunts and data given is total for both.
* SCC copper wire.
** SSC copper wire.

SHUNT FIELD COILS—CONTINUED

	Volts	Amps.	STATIONARY				ADJUSTABLE				ADJUSTABLE			
			J, JN, J-3, FN, DEN, EEN, D-3				J-1 and D-1				J-2 and D-2			
			Turns	Wire	Res.	Form	Turns	SSC Wire	Res.	Form	Turns	SSC Wire	Res.	Form
2-Wire	500-550	100	900	*.004	245 ohms	EN	1500	.003	980 ohms	D-1	1200	.004	480 ohms	D-2
	"	150	"	"	"	"	"	"	"	"	"	"	"	"
	"	200	"	"	"	DEN	"	"	"	"	"	"	"	"
	"	300	"	"	"	"	"	"	"	"	"	"	"	"
	"	450	"	"	"	"	"	"	"	"	"	"	"	"
	"	600	"	"	"	"	"	"	"	"	"	"	"	"
	550	†1200	1000	"	400 ohms	EEN	1100	.004	440 ohms	"	1000	"	800 ohms	"
	200-220	3½					1000	"	400 ohms	J-1	800	"	320 ohms	J-2
	"	7½	500	**.004	200 ohms	J-3	1100	"	440 ohms	"	"	"	"	"
	"	15	375	*.005	100 ohms	D-3	1000	"	400 ohms	D-1	"	"	"	D-2
	"	25	"	"	"	"	"	"	"	"	"	"	"	"
	"	50	"	"	"	"	"	"	"	"	"	"	"	"
	"	75	"	"	"	"	"	"	"	"	"	"	"	"
	"	100	"	"	"	"	"	"	"	"	"	"	"	"
	"	150	"	"	"	"	"	"	"	"	"	"	"	"
	"	200	"	"	"	"	"	"	"	"	"	"	"	"
	"	300	"	"	"	"	"	"	"	"	"	"	"	"

† 1200 amp. meters have two shunts and data given is total for both.
* SCC copper wire
** SSC copper wire.

SHUNT COIL DATA FOR HIGH CAPACITY G-2 CONTINUOUS CURRENT, ASTATIC WATT-HOUR METERS

Volts	Amps.	Turns per Coil	Wire	Total Res
110	2500	500	.005 SSC	280
"	4000	650	.004 SSC	570
"	5000	750	"	660
"	6500	750	"	660
"	8000	750	"	660
"	10000	750	"	660
220	2500	500	.005 SSC	280
"	4000	800	.004 SSC	700
"	5000	800	"	700
"	6500	1000	.003 SSC	880
"	8000	800	.004 SSC	700
"	10000	800	"	700
550	2500	500	.005 SSC	280
"	4000	800	.004 SSC	700
"	5000	800	"	700
"	6500	1000	.003 SSC	880
"	8000	800	.004 SSC	700
"	10000	800	"	700

These meters are supplied with two shunt field coils.

Data as given applies to each coil with exception of resistance which is total for both.

CARD OR TUBE RESISTANCE THOMSON RECORDING WATTMETERS

	Volts	Amps.	Form	Resistance Ohms	Form	Resistance Ohms
2-Wire	50-55	3	J, J-1		J-2	
	"	5	"	287	"	240
	"	10	"	287	"	240
	"	15	"	222	"	240
	"	25	D, D-1	187	D-2	240
	"	50	"	187	"	240
	"	75	"	177	"	240
	"	100	"	177	"	240
	"	150	"	177	"	240
	"	200	"	202	"	240
	"	300	"	247	"	240
	"	450	"	247	"	240
	"	600	"	247	"	240
	100-110	3	J-1	1080	J-2	1000
	"	5	"	1220	"	1000
	"	10	"	980	"	1000
	"	15	"	1030	"	1000
	"	25	D-1	730	D-2	1000
	"	50	"	730	"	1000
	"	75	"	730	"	1000
	"	100	"	730	"	1000
	"	150	"	730	"	1000
	"	200	"	730	"	1000
	"	300	"	730	"	1000
	"	450	"	730	"	1000
	"	600	"	730	"	1000
	110	1200	"	1380	"	1000
	200-220	3	J-1	2830	J-2	3340
	"	5	"	2580	"	3340
	"	10	"	2630	"	3340
	"	15	"	2430	"	3340
	"	25	D-1	2630	D-2	3340
	"	50	"	2630	"	3340
	"	75	"	2630	"	3340
	"	100	"	2630	"	3340
	"	150	D-1	2630	D-2	3340
	"	200	"	2630	"	3340
	"	300	"	2630	"	3340
	"	450	"	2630	"	3340
	"	600	"	2630	"	3340
	220	1200	"	4080	"	3340

CARD OR TUBE RESISTANCE THOMSON RECORDING WATTMETERS

	Volts	Amps.	Form	Resistance Ohms	Form	Resistance Ohms
2-Wire	500–550	3	J–1	9460	J–2	10460
	"	5	"	9460	"	10460
	"	10	"	9460	"	10460
	"	15	"	9460	"	10460
	"	25	D–1	9460	D–2	10460
	"	50	"	9460	"	10460
	"	75	"	9460	"	10460
	"	100	"	9460	"	10460
	"	150	"	9460	"	10460
	"	200	"	9460	"	10460
	"	300	"	9460	"	10460
	"	450	"	9460	"	10460
	"	600	"	9460	"	10460
	550	1200	"	11180	"	10460
3-Wire	200–220	3½	J–1	1080	J–2	1000
	"	7½	"	1550	"	1000
	"	15	D–1	730	D–2	1000
	"	25	"	730	"	1000
	"	50	"	730	"	1000
	"	75	"	730	"	1000
	"	100	"	730	"	1000
	"	150	"	730	"	1000
	"	200	"	730	"	1000
	"	300	"	730	"	1000

TOTAL RESISTANCE AND WATT LOSS POTENTIAL
THOMSON RECORDING WATTMETERS

Form	Resistance Ohms	Watt Loss	Form	Resistance Ohms

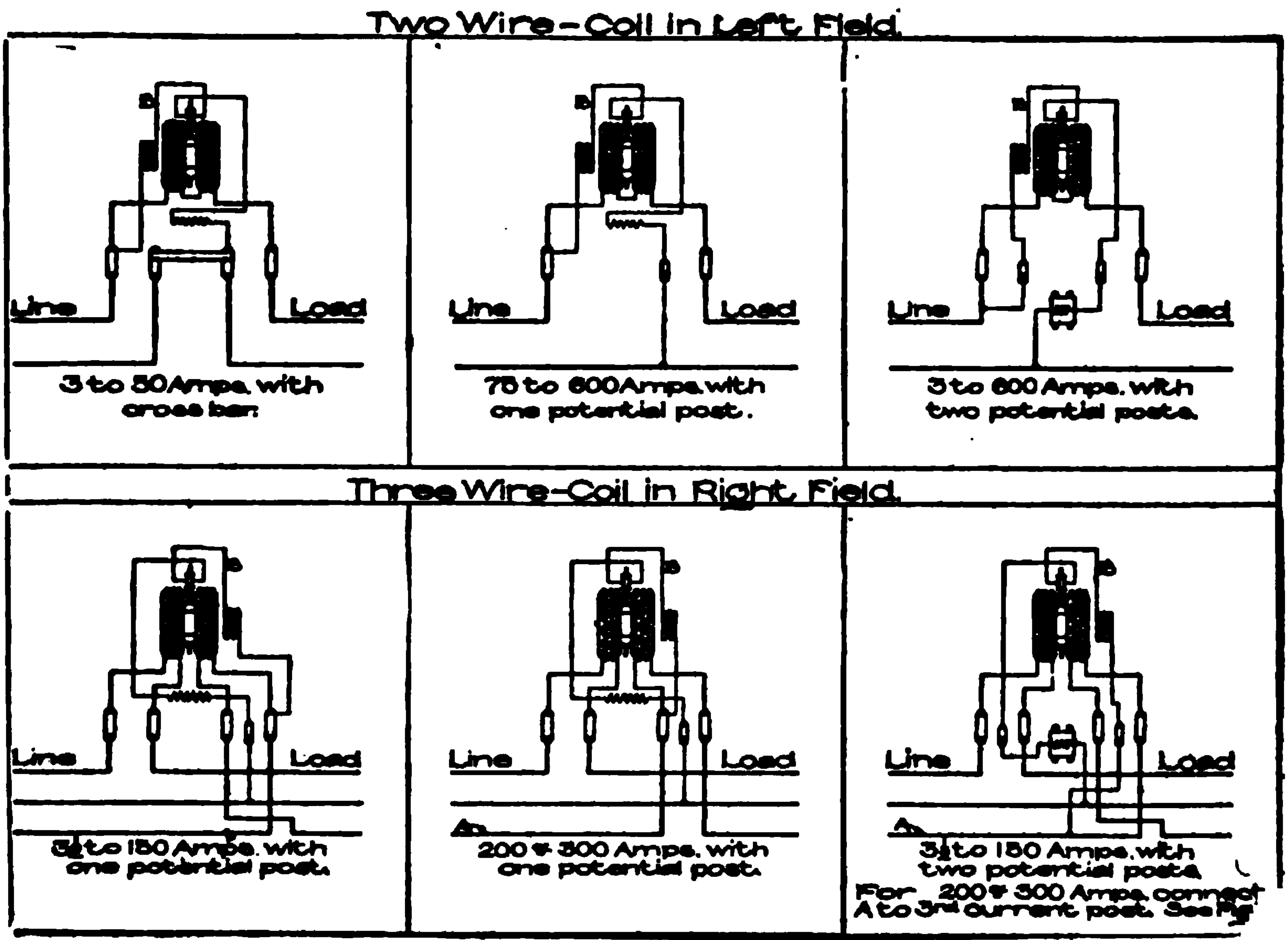
2-Wire

TOTAL RESISTANCE AND WATT LOSS POTENTIAL CIRCUIT THOMSON RECORDING WATTMETERS

	Volts	Amps.	Form	Resistance Ohms	Watt Loss	Form	Resistance Ohms	Watt Loss
2-Wire	220	1200	D-1	5640	8.58	D-2	5000	9.68
	500-550	3	J-1	11620	26.05	J-2	12120	24.92
	"	5	"	11620	26.05	"	12120	24.92
	"	10	"	11620	26.05	"	12120	24.92
	"	15	"	11620	26.05	"	12120	24.92
	"	25	D-1	11620	26.05	D-2	12120	24.92
	"	50	"	11620	26.05	"	12120	24.92
	"	75	"	11620	26.05	"	12120	24.92
	"	100	"	11620	26.05	"	12120	24.92
	"	150	"	11620	26.05	"	12120	24.92
	"	200	"	11620	26.05	"	12120	24.92
	"	300	"	11620	26.05	"	12120	24.92
	"	450	"	11620	26.05	"	12120	24.92
	"	600	"	11620	26.05	"	12120	24.92
	550	1200	"	12800	23.63	"	12120	24.92
3-Wire	200-220	3½	J-1	2660	4.55	J-2	2500	4.84
	"	7½	"	2415	5.02	"	2500	4.84
	"	15	D-1	2310	5.25	"	2500	4.84
	"	25	"	2310	5.25	D-2	2500	4.84
	"	50	"	2310	5.25	"	2500	4.84
	"	75	"	2310	5.25	"	2500	4.84
	"	100	"	2310	5.25	"	2500	4.84
	"	150	"	2310	5.25	"	2500	4.84
	"	200	"	2310	5.25	"	2500	4.84
	"	300	"	2310	5.25	"	2500	4.84

TOTAL RESISTANCE AND WATT LOSS IN POTENTIAL CIRCUIT OF HIGH CAPACITY G-2 CONTINUOUS CURRENT ASTATIC WATT-HOUR METERS

Volts	Amps.	Res. Ohms	Watt Loss
110	2500	1700	7.12
"	4000	1880	6.45
"	5000	1900	6.35
"	6500	1800	6.77
"	8000	2020	5.96
"	10000	2020	5.96
220	2500	4650	10.4
"	4000	4800	10.2
"	5000	4800	10.2
"	6500	5370	9.0
"	8000	4800	10.2
"	10000	4800	10.2
550	2500	11600	26.1
"	4000	12000	25.2
"	5000	12000	25.2
"	6500	13400	22.4
"	8000	12000	25.2
"	10000	12000	25.2



Thomson Continuous Current Watt-hour Meters, Recent Types

The "Thomson Recording Wattmeters" of the types already described were superseded in 1904 by the Type C Thomson watt-hour meters, which, while based on the same fundamental principles, were essentially different in details of construction (Fig. 417).

Thomson continuous current watt-hour meters of types C, C-5, C-6, C-7, C-9, CP, CP-2, CP-3, CP-4, CQ, CQ-2, CS, CS-2, CB-4, G-2 and G-3, comprise those watt-hour meters **with spherical armatures.**

Of these types, Type C-6, C-7, C-9 and CP-4 are the present standard continuous current watt-hour meters, the other types having been superseded. These meters all use the spherical eight-coil armature wound on a pressed paper core. These are wound of enamel acetate coated wire, and after completion are protected by a coat of "kapak" insulation baked on.

The **magnets,** four in number, are arranged in pairs, which are astatically mounted on a rigid shoe.

The **jewels** are made of Ceylon sapphires for the lower capacities up to 50 kilowatts, and cupped diamonds are used in all continuous current meters of 50 kilowatts capacity and over.

The **pivots,** which are removable, are made from steel wire, and are hardened, ground and highly polished with spherical tips.

The **registers** are all of the four-dial type (Fig. 418), reading directly in kilowatt-hours, except in a few of the higher capacities, where a register constant of 10, 100 or 1,000 is used, as indicated on the dial face. Each register is stamped on the back with a number expressing the ratio between revolutions of the worm wheel, or wheel meshing with the worm on the moving element shaft, and revolutions of the first dial hand, or the register ratio. The ratio of the worm gear in all cases being 100 : 1, from the above the following formula is derived:

Test constant $K_h \times 100 \times$ the **register ratio** = the number of watt-hours corresponding to one revolution of the most rapidly moving dial hand. By substituting two of the above factors, the third may readily be determined. (See Chapter XV.)

On page 752 is given an explanation of the **signtficance of the letters used in designating these types** of Thomson continuous current watt-hour meters:

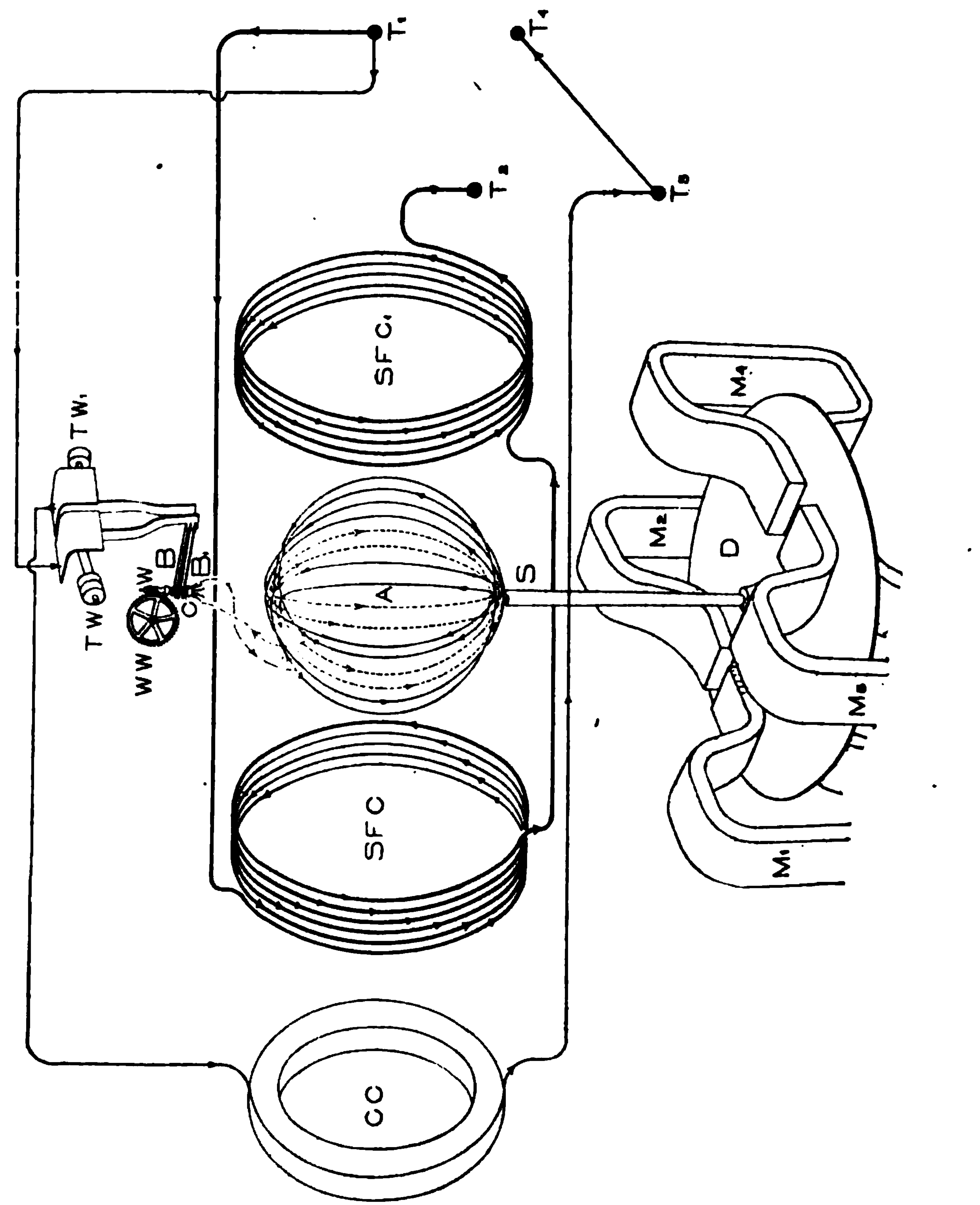


FIG. 417.—A, Armature; BB′, Brushes; C, Commutator; CC, Friction Compensation Coil; D, Disk; M_1, M_2, M_3, M_4, Drag Magnets; S, Shaft; SF C, SF C′, Series Field Coils; T_1, T_2, T_3, T_4, Terminals; TW, TW_1, Tension Weights for Brushes; W, Worm; WW, Worm Wheel.

C —House service type, two- and three-wire; capacities ranging from 5 to 600 (inclusive) amperes, and voltages ranging from 0 to 800 volts.

C-5 —Essentially the same as C-6, but back connected and in capacities of Types C-6 and C-7.

C-6 —Superseded Type C in capacities up to 250 volts, inclusive.

C-7 —Superseded Type C in capacities above 250 volts.

C-9 —Superseded Type C-5, with omission of supporting lugs and altered potential stud arrangement.

CP —Prepayment type, used with separate prepayment device.

CP-2—Prepayment type in combination with C-6 watt-hour meter.

CP-3—Supersedes CP-2, with changed mechanical details.

CP-4—Supersedes CP-3 and is the same, except operating knob details, and slight changes.

CQ —House service type, with four pole armature.

CQ-2—Same as CQ, except back connected.

CS —Astatic switchboard type.

CS-2—Same as CS, except that it is front connected.

CB-4—Portable rotating standard with C-6 characteristics.

G-2 —Astatic switchboard type, similar to Type CS, except that current coils are bus-bar type instead of circular.

G-3 —Same as Type G-2, except that cover consists of two parts, a metal subbase and glass cover.

The type C Thomson watt-hour meter was designed for house service for use upon continuous current, two and three-wire, in capacities of 5, 10, 15, 25, 50, 75, 100, 150, 300 and 600 amperes, 0 to 800 volts, three-wire; and 5 to 300 amperes in like steps for 200 to 800 volts, three-wire.

For meters up to 250 volts, the resistance was wound on a tube and mounted on the inside of the meter on the back.

For meters above 250 volts up to and including 600 volts, the resistance was wound on a tube and mounted in an external cage on the meter back. For meters above 600 volts the resistance was wound on tubes and mounted in a separate box. The finish of the meter was dull black japan. The cover was provided with a glass window for reading the meter register. The meter when required was furnished with glass cover.

The leading in wires entered into binding posts located at the sides of the meter.

This type was in production from July, 1904, to November, 1905.

The Type C Thomson watt-hour meters, in capacities up to 250 volts, have been superseded by the Type C-6. In capacities above 250 volts they have been superseded by the Type C-7. The Types C-6 and C-7 watt-hour meters are built in the same current capacities as the Type

FIG. 418.—Register, Four Dial Type.

C, the Type C-7 meter being built for use on two-wire circuits only. The Type C-6 meter is furnished with the combined shunt and resistance, and upon the Type C-7 meter the separate shunt field coil is used. For meters up to 600 volts the resistance is wound upon tubes and mounted in an external cage upon the meter back. For meters above 600 volts, the resistance is wound on tubes and mounted in a separate box. The finish is dull black japan, covering being provided with glass windows for reading the meter register, and when so desired molded glass cover can be furnished (Figs. 419, 420 and 421).

The leading in wires enter into binding posts located at the sides of the meter.

Types C-6 and C-7 have been in production from November, 1905, to date.

The Type C-5 Thomson watt-hour meter was essentially the Type C-6, but back connected. It was built in similar capacities as the Types C-6 and C-7. Meters up to 250 volts were equipped with combined shunts and resistances; above this voltage the resistance being wound on tubes and mounted in a separate box.

This type of meter was finished in dull black japan, the cover being provided with a glass window for reading the meter register. Moulded glass covers were furnished whenever desired. This type of meter has

External View of Thomson, Type C-6, Continuous Current Watt-hour Meter.

Internal View of Thomson, Type C-6, Continuous Current Watt-hour Meter.

Fig 419.—Thomson, Type C-6 Watt-hour Meter.

been superseded by the present Type C-9. The difference between Types C-5 and C-9 watt-hour meters lies in the omission of supporting lugs on the Type C-9 meter and the vertical arrangement of the potential studs (Figs. 422 and 423).

Type C-9 has been in production from November, 1905, to date.

The Type CP Thomson prepayment watt-hour meter is similar to the Type C-6, except in the number of terminals and a contact making register.

FIG. 420.—External View of Thomson, Type C-7 Watt-hour Meter.

It is built in capacities of 3, 5, 10, 15 and 25 amperes, 100 to 250 volts, two-wire, and 200 to 250 volts three-wire. It is used in connection with a separate prepayment device.

The Type CP-2 Thomson prepayment watt-hour meter is a combination of the prepayment mechanism of the separate prepayment attachment and the Type C-6 watt-hour meter.

This type of meter was built in capacities similar to the Type CP prepayment watt-hour meter and was adapted for either a 10 cent or 25 cent coin.

Finish was similar to the Type C-6.

The Type CP-3 Thomson prepayment watt-hour meter supersedes the Type CP-2. The principle of operation of the CP-3 was similar to the

FIG. 421—Internal View of Thomson, Type C-7 Watt-hour Meter.

CP-2, but they differed greatly in mechanical details, changes being made to provide a more reliable and convenient device (Fig. 424).

The Type CP-4 Thomson prepayment watt-hour meter supersedes the Type CP-3, and is the same electrically and mechanically, except that the operating knob is fastened in the cover and operates the prepayment mechanism through a driving dog preventing any injury to the mechanism by strains on the knob.

The Type CQ Thomson watt-hour meter designed for house service, continuous current, is built in capacities of 50, 75, 100, 200 and 400 amperes, 0 to 800 volts, two-wire; and 50, 75, 100 and 200 amperes, 200 to 800 volts, three-wire (Fig. 425).

The meter has a four-pole armature construction and the field coils are formed in quadrants surrounding the four-pole armature as

Fig. 422 —External View of Thomson, Type C-9 Watt-hour Meter.

completely as possible, this construction minimizing the effect of stray fields (Fig 426).

For watt-hour meters up to 300 volts, the resistance is wound upon tubes and mounted in an external cage upon the meter back. Above 300 volts, the resistance is wound on tubes and mounted in a separate box.

The leading-in wires enter into binding posts located at the side of the meter.

The CQ Type has been in production from May, 1909, to date.

The Type CQ-2 Thomson watt-hour meter differs only from the Type CQ in that it is back connected.

The CQ-2 Type has been in production from November, 1909, to date.

The Type CS Thomson watt-hour meter designed for switchboard service, continuous current, is built in capacities of 50, 75, 100, 150, 200,

FIG. 423. Internal View of Thomson, Type C-9 Watt-hour Meter

300, 400, 600, 800, 1,200 and 1,500 amperes, 0 to 800 volts two- and three-wire (Fig. 427).

The meter has two spherical armatures mounted astatically on the same shaft.

The series field is constructed of copper punchings joined in such a way that the current divides and flows completely around and close to each armature, so as to give a maximum influence of the working flux.

The resistance for all Type CS watt-hour meters is wound upon tubes and mounted in a separate box.

The meter has a glass cover and is finished in dull black japan, the prominent internal parts being finished in polished brass

FIG. 424—Thomson, Prepayment, Type CP-3 Watt-hour Meter.

The CS Type has been in production from November, 1907, to date

The CS-2 Thomson watt-hour meter is the same as the CS, except that it is front connected, has a metal cover and the internal parts left unpolished (Fig. 428).

The CS-2 Type has been in production from August, 1910, to date

The Type CB-4 Thomson portable test meter, or rotating standard, is built in capacities of 1, 2, 10, 20 and 40 amperes, 110 volt and 110

FIG. 425.—Thomson, Type CQ Watt-hour Meter.

and 220 volt; 5, 10, 50 and 100 amperes, 110 volt and 110 and 220 volt. The electrical characteristics are similar to the Type C-6 (Figs. 429 and 430).

The Type G-2 Thomson watt-hour meter was designed for switchboard service upon continuous current, two- and three-wire circuits.

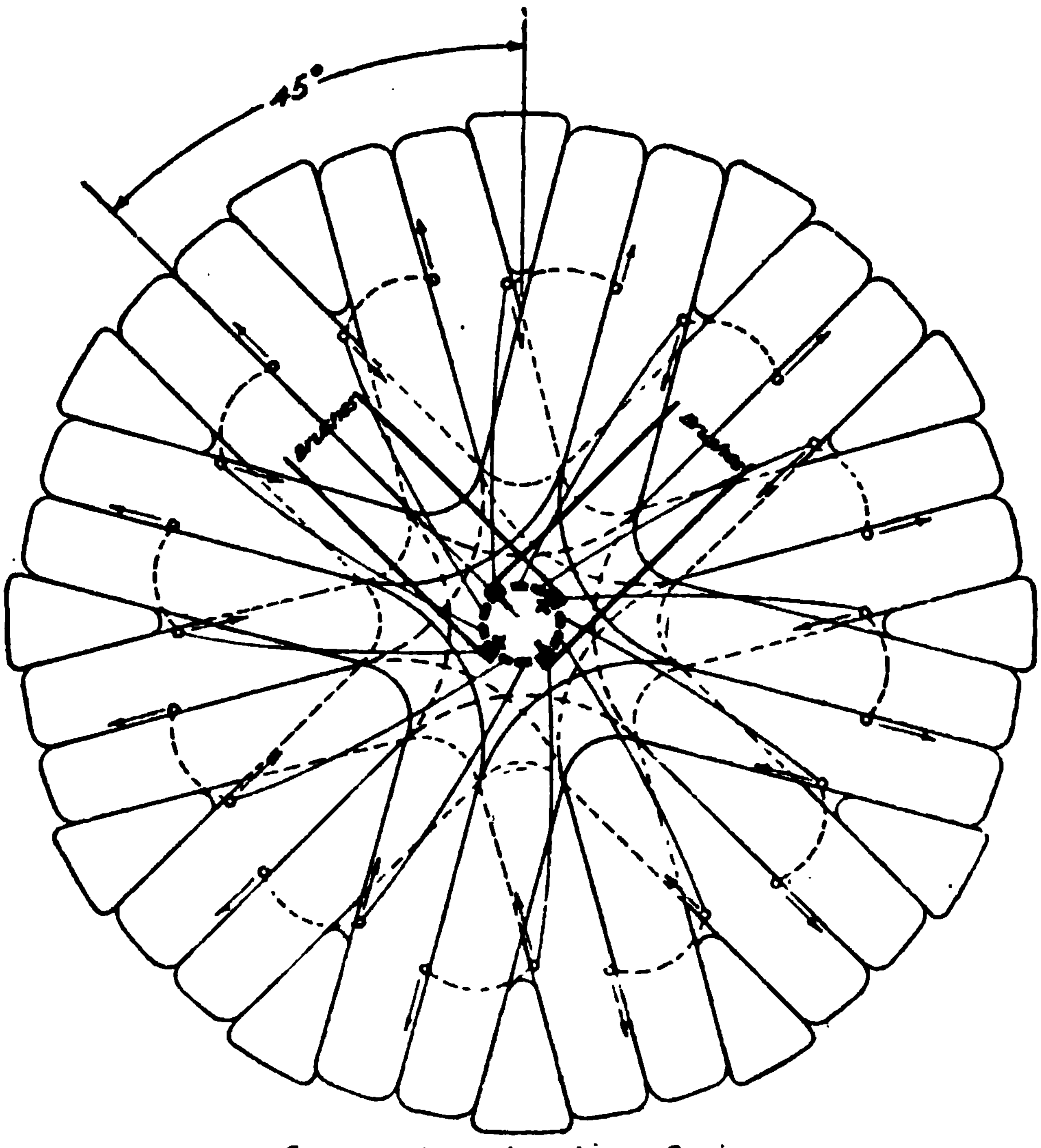


FIG. 426.—Armature of Thomson, Type CQ Watt-hour Meter.

It is built in capacities of 2,000, 3,000, 4,000, 6,000, 8,000 10,000 and 15,000 amperes, 0 to 800 volts, two-wire, and 2,000, 3,000, 4,000 and 6,000 amperes, 200 to 800 volts, three-wire (Fig. 431).

The resistance for all Type G-2 watt-hour meters is wound upon tubes and mounted in a separate box. This type of watt-hour meter uses the astatic armature of the spherical type and the shielded damping mechanism similar to the Type CS watt-hour meter.

has a rectangular glass cover and is finished in polished copper and brass. The cover is secured to the switchboard by four bolts.

The G-2 Type has been in production from May, 1908, to date.

The Type G-3 Thomson watt-hour meter is similar in every respect to the Type G-2, except that the cover or case consists of two parts, a metal subbase which is bolted to the switchboard, and a

FIG. 427.—Thomson, Type CS Watt-hour Meter

glass cover which is fastened to this subbase by means of screws This construction makes the cover removable from the front.

The G-3 Type has been in production from January, 1911, to date

The **testing formula** for the above types of Thomson watt-hour meters is as follows:

$$\text{Watts} = \frac{3{,}600 \times K_h \times R}{S}$$

K_h = constant as marked on disk, or watt-hour constant

R = number of revolutions of disk.

S = time in seconds.

(See also Chapters XV and VII)

Fig. 428.—Thomson, Type CS-2 Watt-hour Meter

Two-hour overload capacity of 150 per cent of the full load rating of these watt-hour meters is allowed.

Registers are all direct reading, except where a register constant is marked on a register. The only register constants used on registers

FIG. 429.—External View of Thomson, Type CB-4 Rotating Standard.

are 10 and 100. The first dial reads directly in kilowatt-hours, each division being equal to one kilowatt-hour.

For **Tables of Constants,** see Chapter XV.

Data on performance of C-6, C-7 and C-9 watt-hour meters are given below:

Speed of moving element at full load........ 46 rev. per min
Torque at full load .... 170 mm-g.

Weight of moving element	97 to 107 grammes, according to capacity
Ratio of torque to weight	1.78 to 1.61
Volt drop in series field, 150 amp.	0.06
Volt drop in series field, 5 amp.	1.15
Watt loss in series coil, 5 amp.	5.7
Watt loss in series coil, 150 amp	9.5
Watt loss in potential circuit, 110 volt	5.1

FIG. 430.—Internal View of Thomson, Type C B-4 Rotating Standard.

FIG. 431—Thomson, Type G-2 Watt-hour Meter.

Similar data for CQ and CQ-2 watt-hour meters follows:

Speed of moving element at full load	46 rev. per min.
Torque at full load	111 mm-g.
Weight of moving element	96 grammes
Ratio of torque to weight	1.16
Volt drop in series field, 50 amp.	0.15
Watt loss in series coil, 50 amp.	7.5
Watt loss in potential circuit, 110 volts	9.25

Similar data for CS and CS-2 watt-hour meters follows:

Speed of moving element at full load	46 rev. per min.
Torque at full load, 400 amp.	190 mm-g.
Torque at full load, 1,200 amp.	258 mm-g.
Torque at full load, 1,500 amp.	315 mm-g.
Weight of moving element, 50 to 600 amp.	173 grammes
Weight of moving element, 800 to 1,500 amp.	180 grammes
Ratio of torque to weight	1.75
Watt loss in potential circuit, 110 volts	6.2

Some data on G-2 and G-3 watt-hour meters follows:

Speed of moving element at full load	37 rev. per min.
Torque of moving element	150 to 300 grammes
Weight of moving element	175 to 200 grammes

Types which are merely adaptations of other types will have similar data of performance.

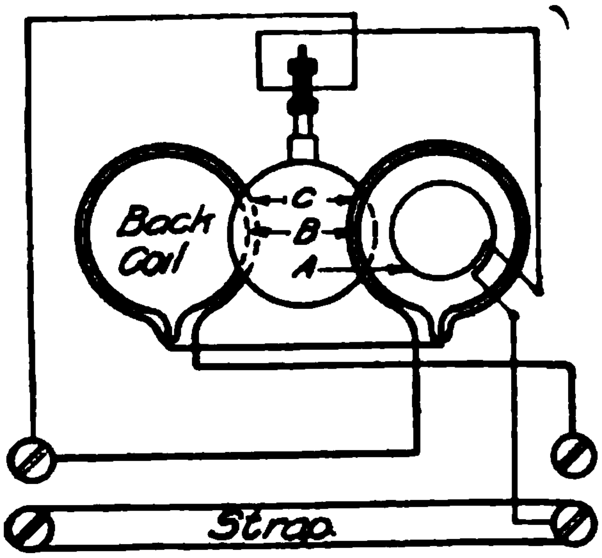
The size of terminal holes is the same throughout all lines of the General Electric (Thomson) watt-hour meters and the sizes are in accordance with the following tables:

Series terminals,	3 to 10 amp.	1/4 in.	
	15 " 25 "	5/16 "	
	50 "	3/8 "	
	75 "	7/16 "	
	100 to 150 "	1/2 "	cable with lug.
	300 "	two 1/2 "	cables with lug.
	600 "	four 1/2 "	cables with lug.

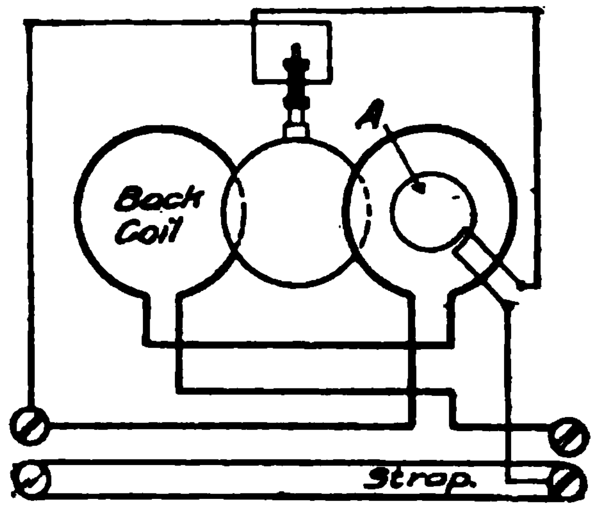
Shunt Resistance, Armature Resistance and Size of Wire

Resistance of shunt field coil, Type C meter	66 ohms
Resistance of armature, Type C meter	823 "
Series resistance, Type C meter	1,541 "
Total resistance potential circuit, Type C meter	2,430 "
Ampere turns series field, Type C meter	300
Resistance of armature, Type C-6 meter	930 ohms
Number of effective turns in shunt field coil, Type C-6 meter	800 to 2,000
Shunt field coil, Type C-7 meter	1,200 turns
Resistance shunt field coil	300 ohms

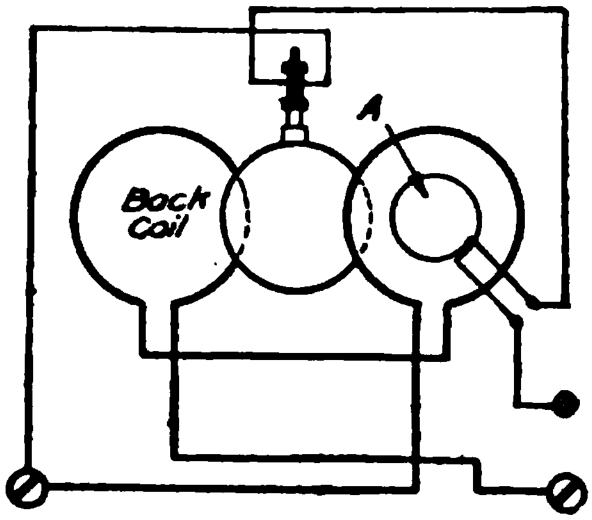
For Types C-5 and C-9 use same data as for the Type C-6.



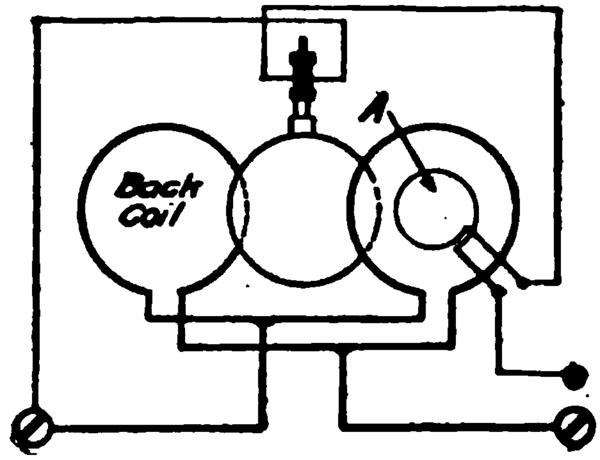
5-15 Amp. 100–250 Volts, 2-wire.



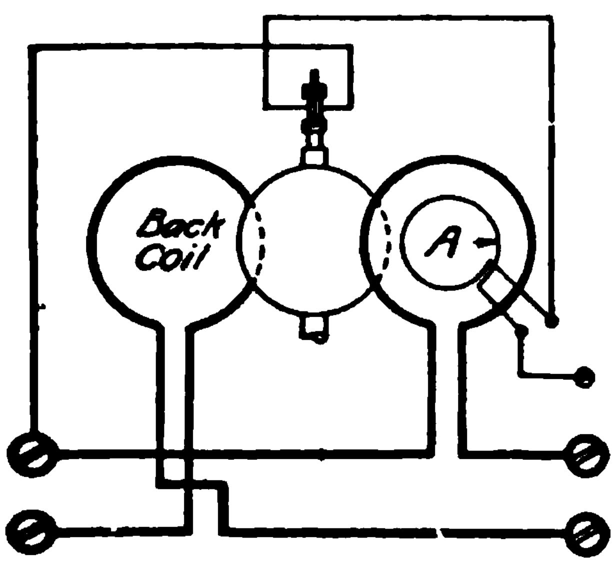
25-50 Amp. 100–250 Volts, 2-wire.



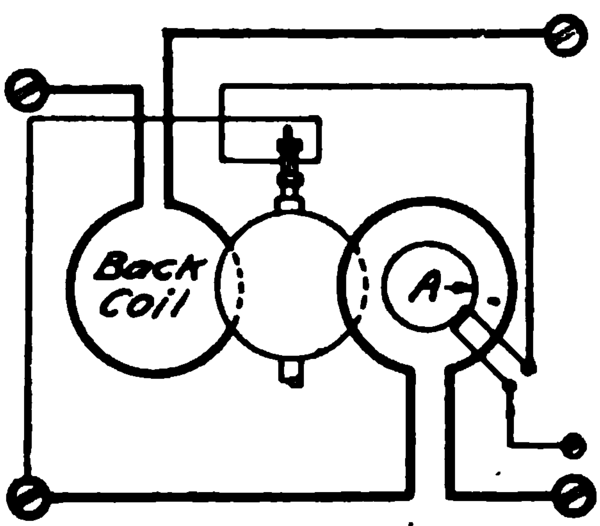
75-300 Amp. 100–250 Vclts, 2-wire.



600 Amp. 100–250 Volts, 2-wire.

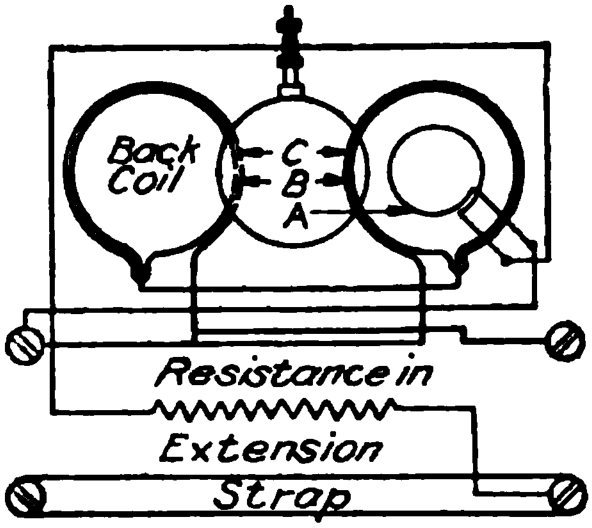


5-50 Amp. 200–500 Volts, 3-wire.

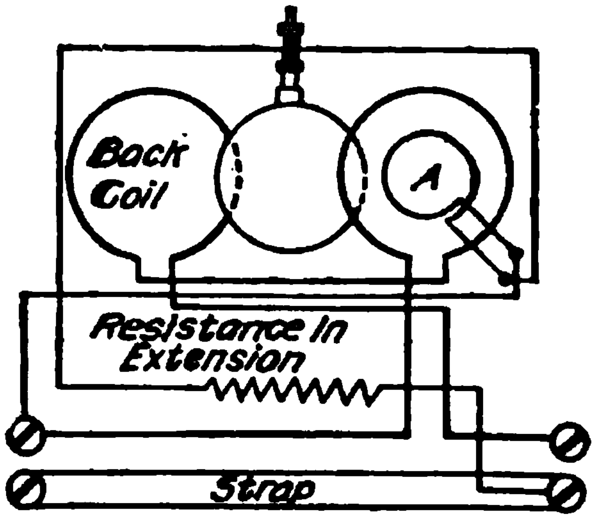


75-300 Amp. 200–500 Volts, 3-wire.

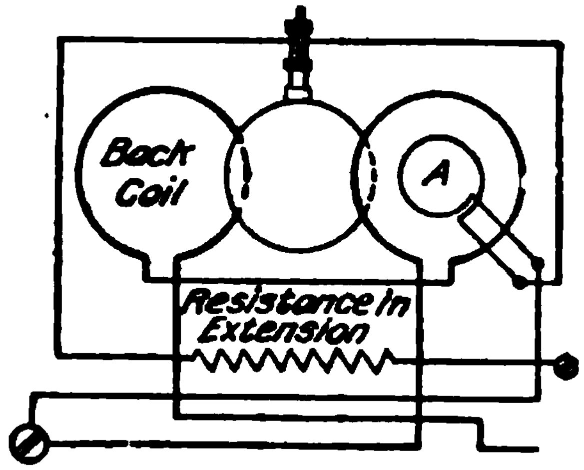
FIG. 432.—Diagrams of Internal Connections of Thomson, Types C and C-6 Watt-hour Meters. Service Enters on the Left.



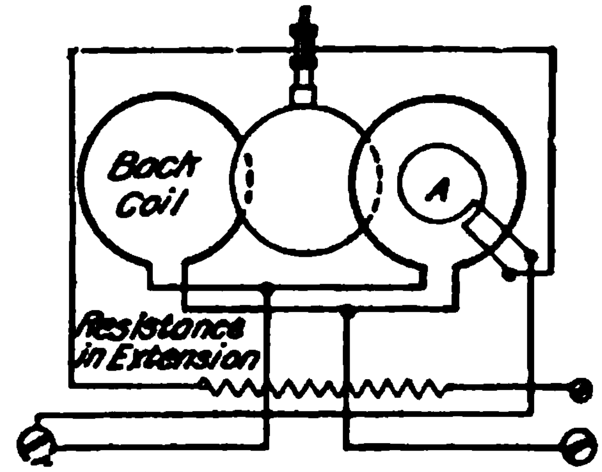
5–15 Amperes, 250–800 Volts, 2-wire.



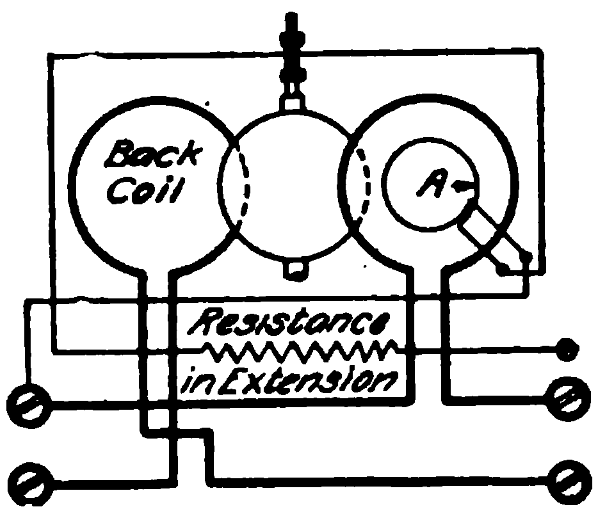
25–50 Amperes, 250–800 Volts, 2-wire.



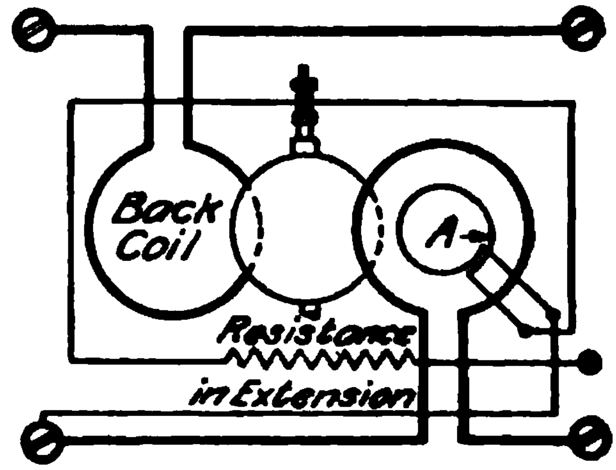
75–300 Amperes, 250–800 Volts, 2-wire.



600 Amperes, 250–800 Volts, 2-wire.



5–50 Amperes, 250–800 Volts, 3-wire.



75–300 Amperes, 501–800 Volts, 3-wire.

'IG. 433.—Diagrams of Internal Connections of Thomson, Types C and C-7 Watt-hour Meters. Service Enters on the Left.

The following **instructions for installing** some of these types have been issued by the manufacturer.

All these watt-hour meters have a jewel bearing and should be handled with care. Some types of meters have a shipping device

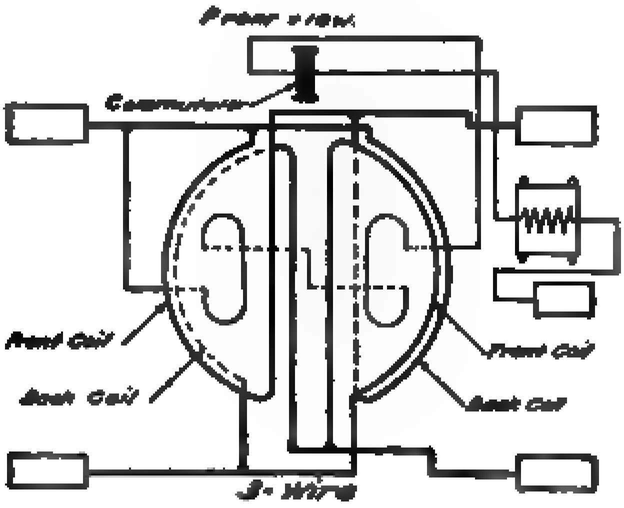


FIG. 434.—Internal Connections of Thomson Types of CQ and CQ-2, Watt-hour Meters. Resistance for Type CQ Meters up to 300 Volts, 2-wire and 600 Volts, 3-wire Mounted in a Cage upon the Meter Back. Resistance for Type CQ Meters above 300 Volts, 2-wire and 600 Volts, 3-wire, all Type CQ-2 Meters and Special Type CQ Meters Mounted in a Separate Box.

which holds the disk of the meter in place, preventing any damage to it or the jewel in transportation. This should be used in transporting same to and from the point of installation and should not be removed nor the moving element lowered on the jewel until all preliminary work of installation has been completed.

Care and judgment must be used in deciding upon a proper location for it. A dry, light place, as free from vibration as possible should be selected.

Meters should be inspected to see that they operate freely on light

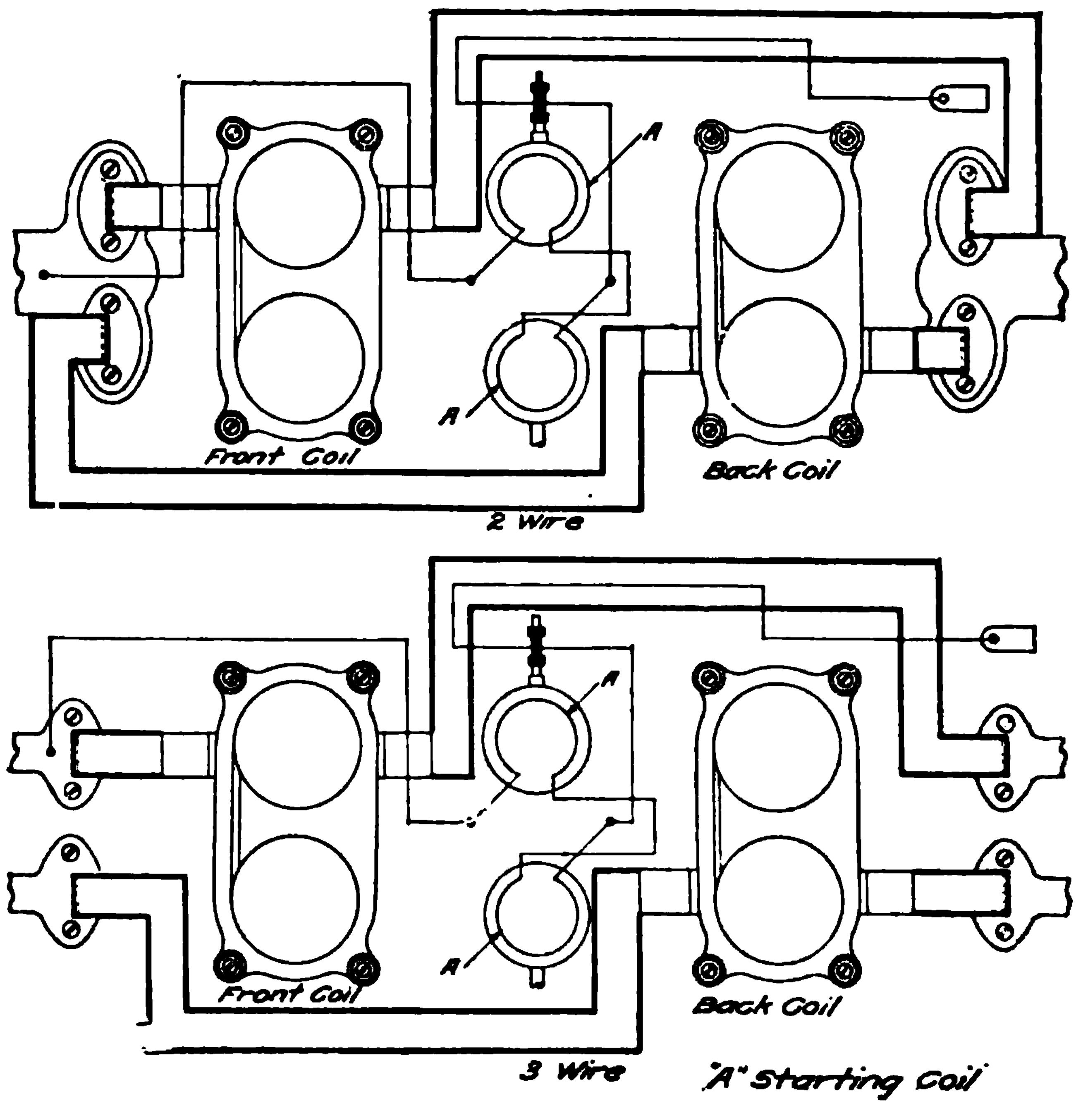


FIG. 435. Internal Connections of Thomson, Type CS-2 Watt-hour Meters. Service Enters on the Left.

loads before leaving them, and to see that the top bearing is set midway between the shoulder and top of the shaft.

The adjustment of the brushes should be noted. In no case should they be left sparking at the commutator. Diagrams of connections and dimensions of some of the foregoing types are given in Figs. 432 to 455.

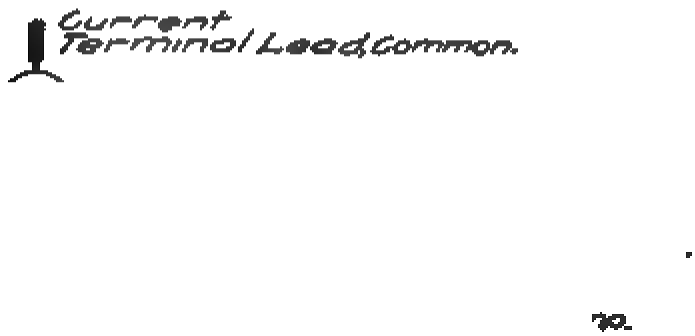


FIG. 436.—Internal Current Circuit Connections of Thomson, Type CB 4 Continuous Current Rotating Standard, 1 to 40 Amperes

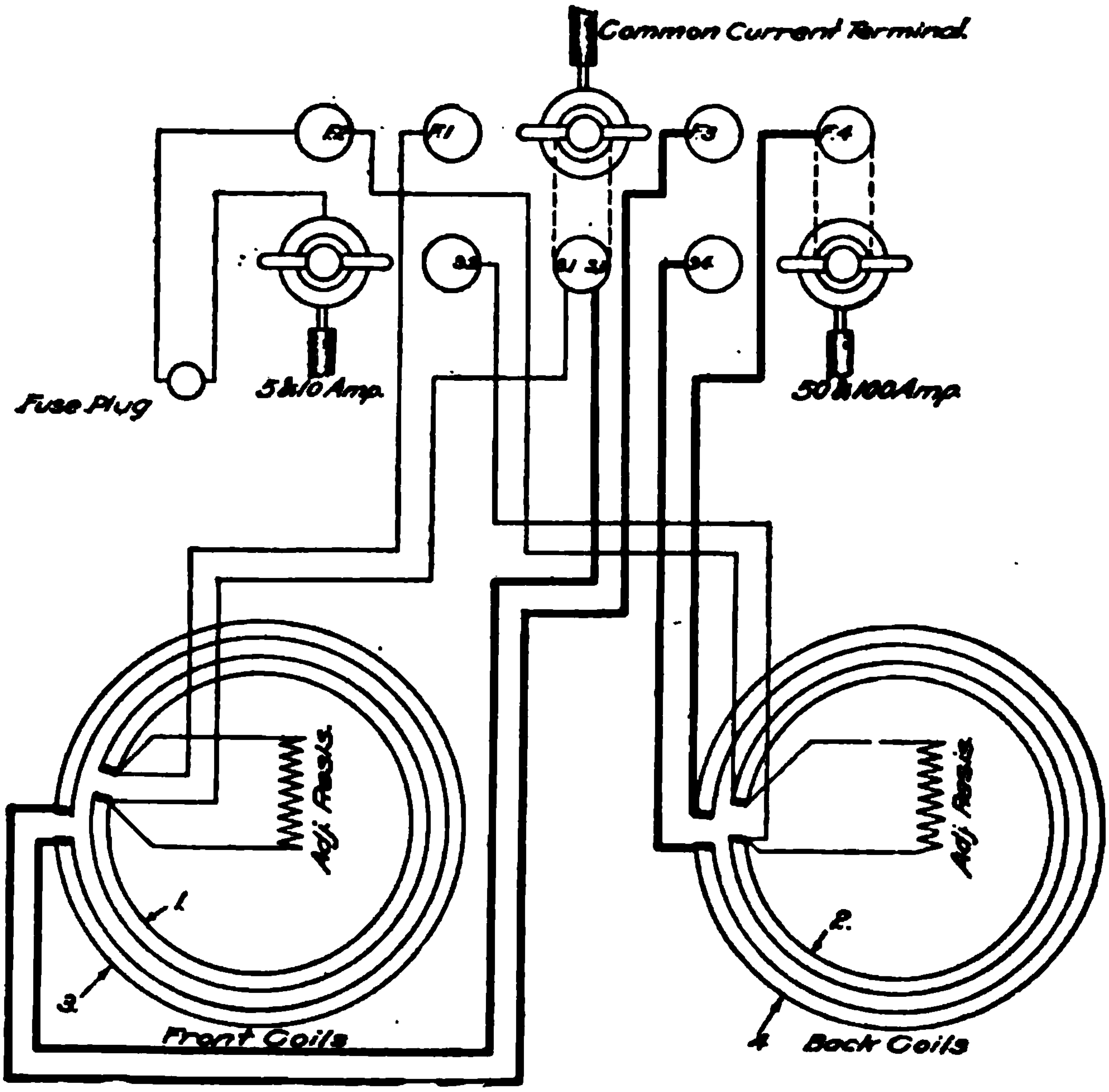


FIG. 437.—Internal Current Circuit Connections of Thomson, Type CB-4, Continuous Current Rotating Standard, 5 to 100 Amperes.

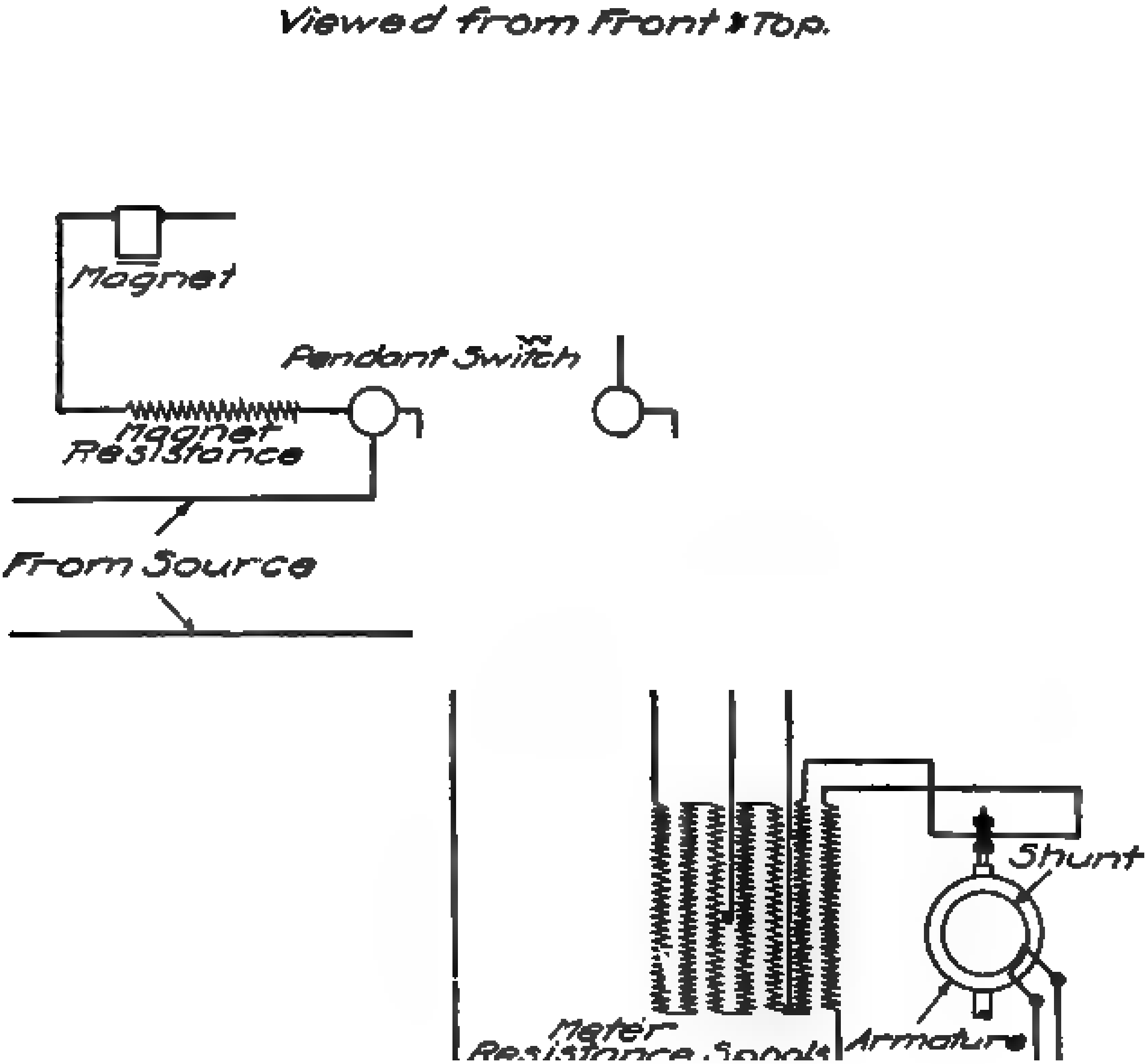


FIG 438.—Internal Potential Circuit Connections of Single Voltage (100–125 Volts), Thomson, Type CB-4 Continuous Current Rotating Standard, 1-2-10-20-40 Amperes, 5-10-50-100 Amperes. Viewed from Front and Top. Heating Key down for Heating Position. Heating Key up for Working Position.

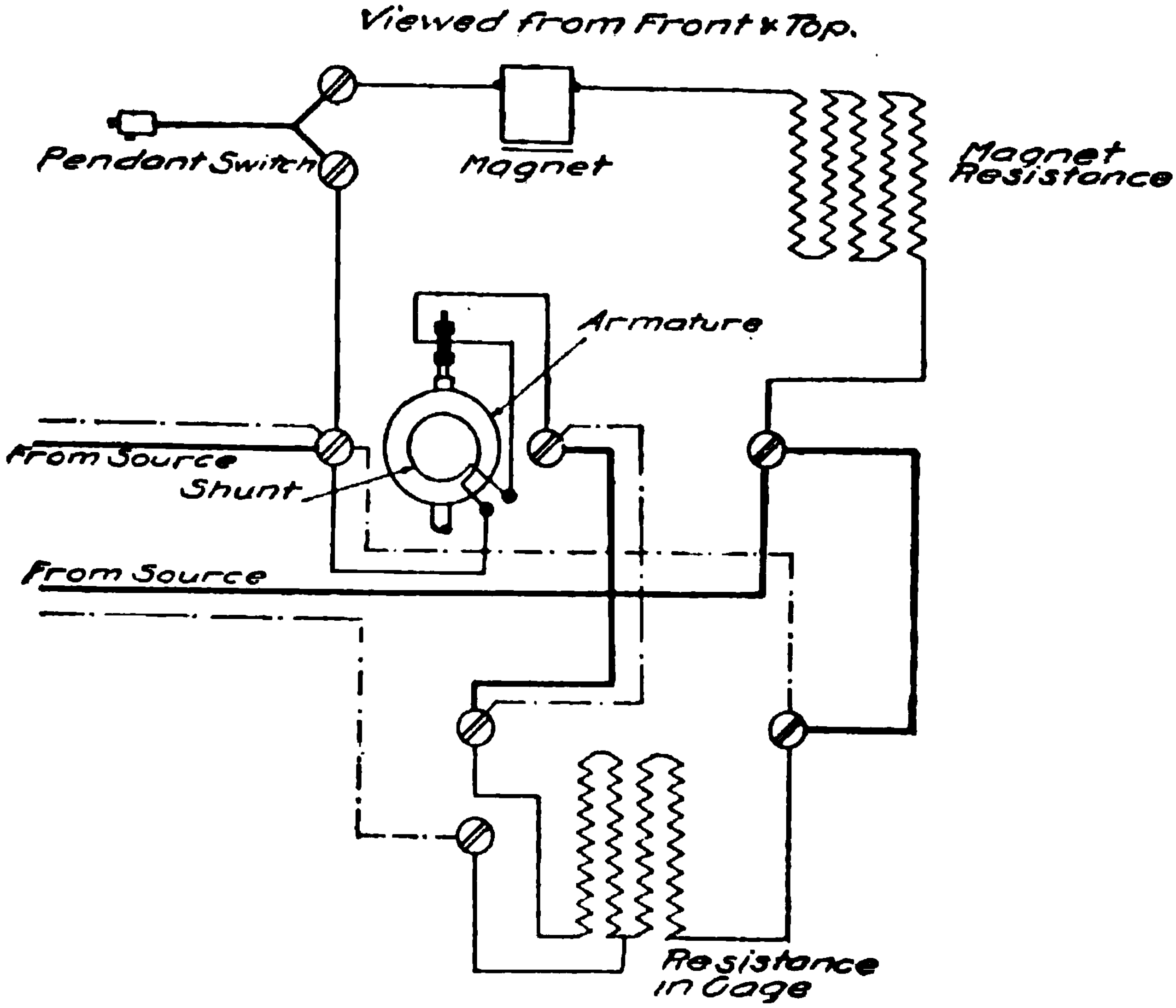


FIG. 439.—Internal Potential Circuit Connections of Single Voltage (200–250 Volts), Thomson, Type CB-4 Continuous Circuit Rotating Standard, 1–2–10–20–40 Amperes, 5–10–50–100 Amperes. Viewed from Front and Top. Heavy Lines show Working Connections. Dash and Dot Lines show Heating Connections.

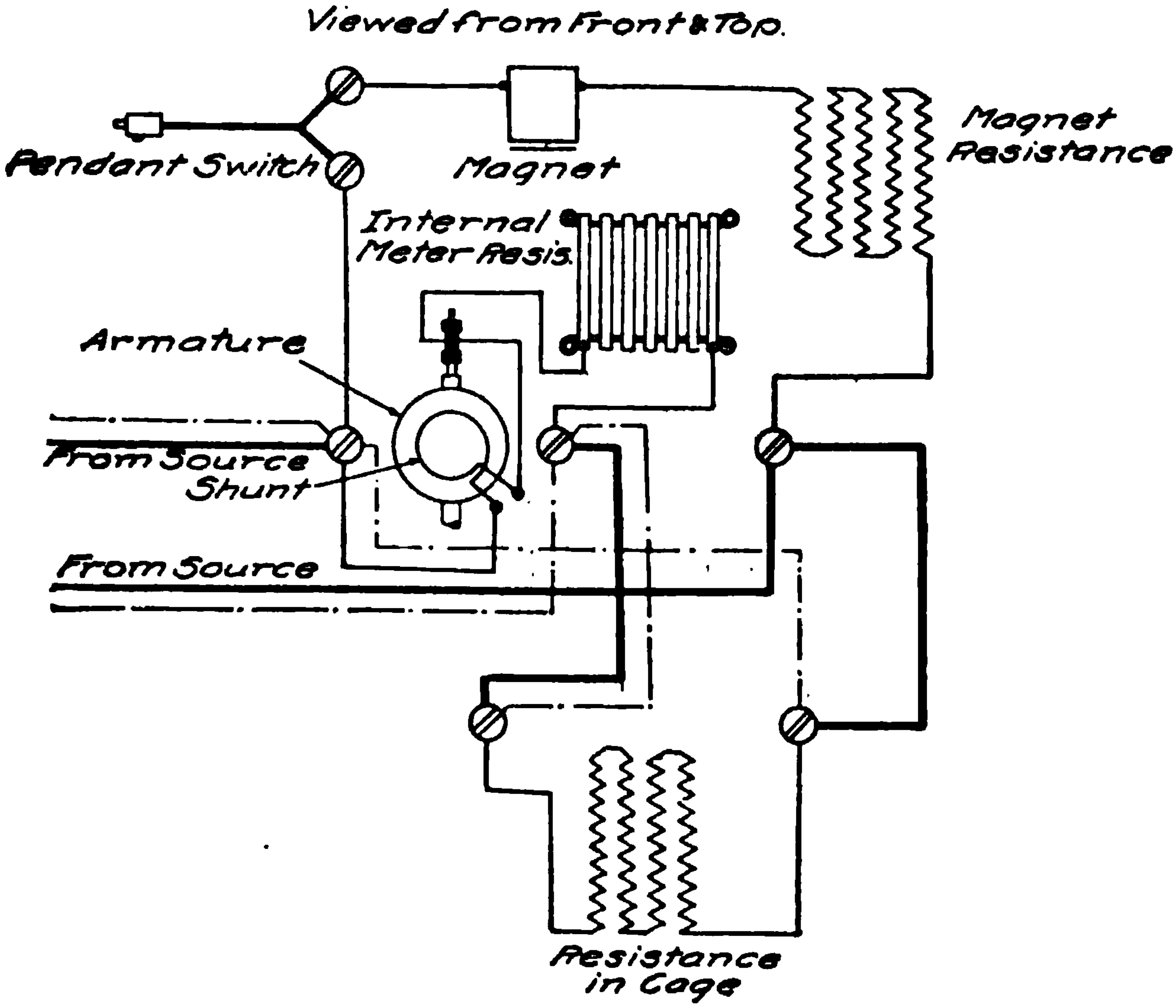


FIG. 440.—Internal Potential Circuit Connections of Single Voltage (600–550 Volts), Thomson, Type CB-4 Continuous Current Rotating Standard, 1–2–10–20–40 Amperes, 5–10–50–100 Amperes. Viewed from Front and Top. Heavy Lines show Working Connections. Dash and Dot Lines show Heating Conn ctions.

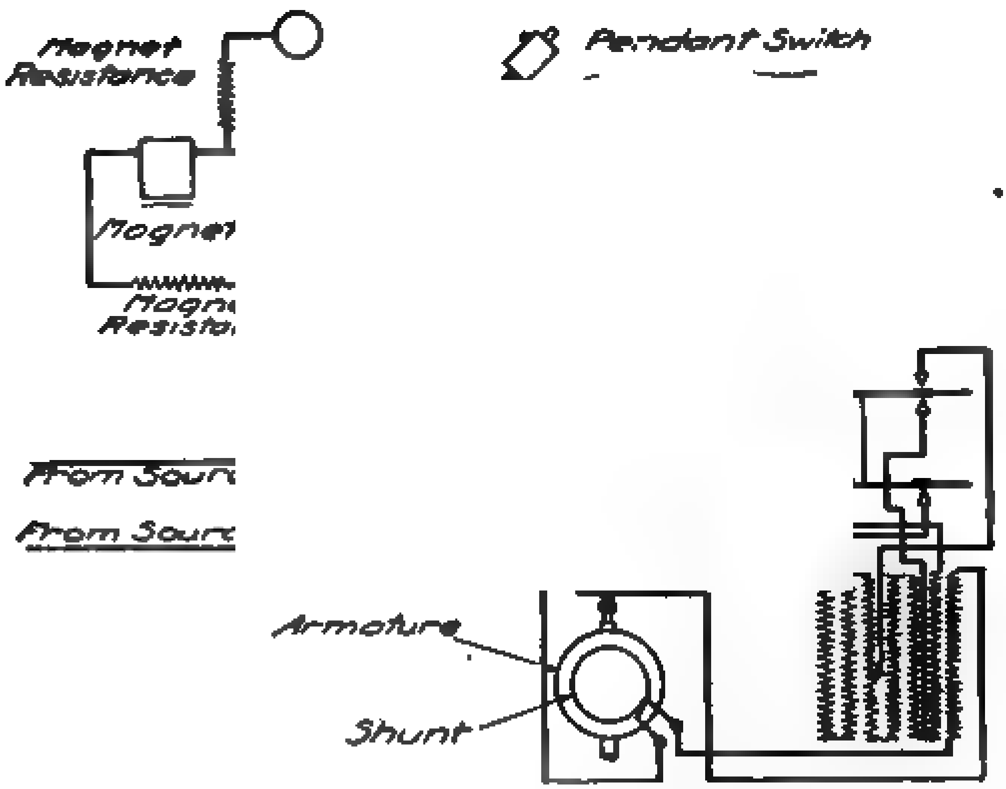


FIG. 441.—Internal Potential Circuit Connections for 100–125 Volt Side of Double Voltage. Thomson, Type CB-4, Continuous Current Rotating Standard, 1-2-10-20-40 Amperes, 5-10-50-100 Amperes. Heating Key Down for Heating Position. Heating Key Up for Working Position.

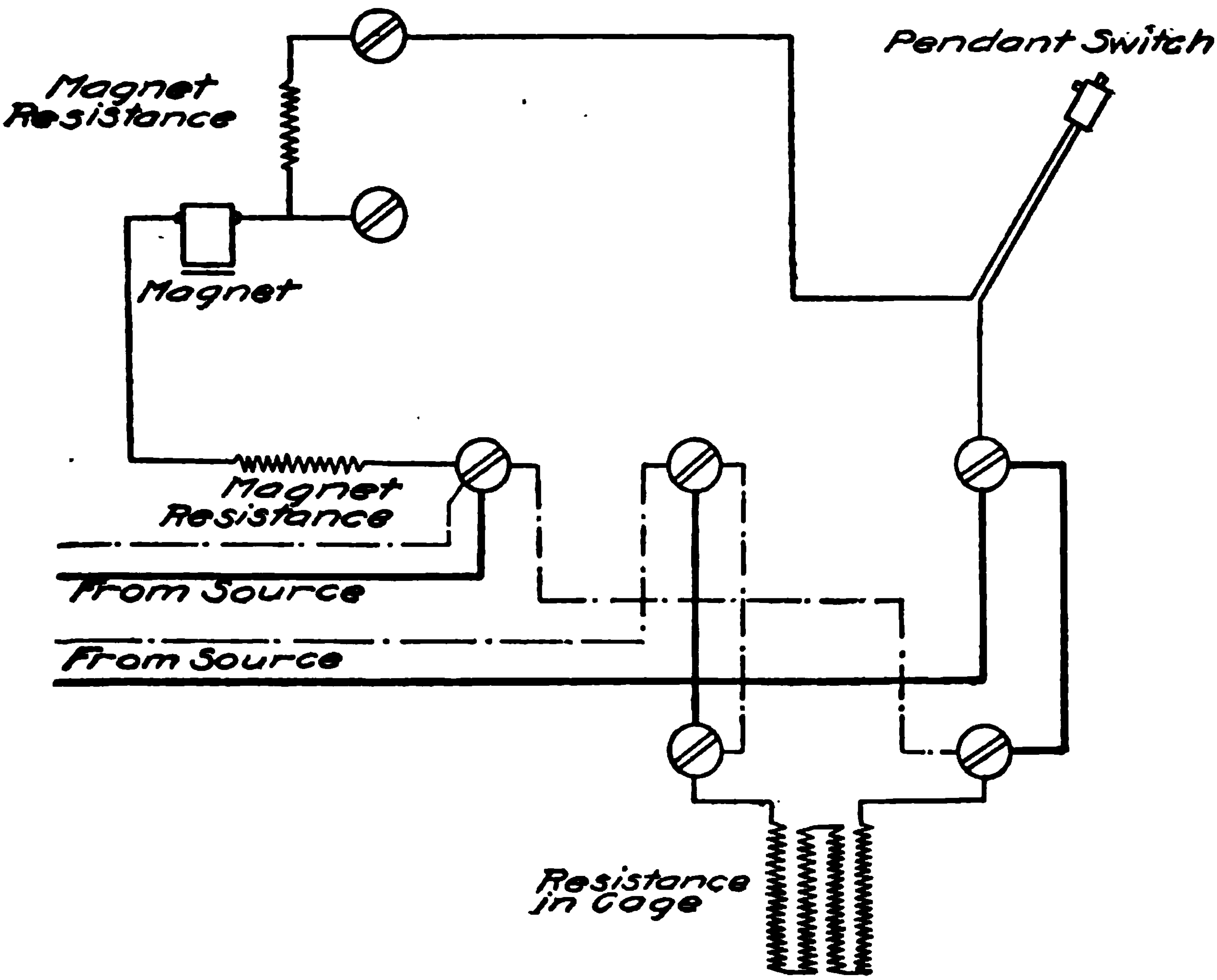


FIG. 442.—Internal Potential Circuit Connections for 200–250 Volt Side of Double Voltage, Thomson, Type CB-4, Continuous Current Rotating Standard, 1–2–10–20–40 Amperes, 1–5–10–50–100 Amperes. Heavy Lines show Working Connections. Dash and Dot Lines show Heating Connections.

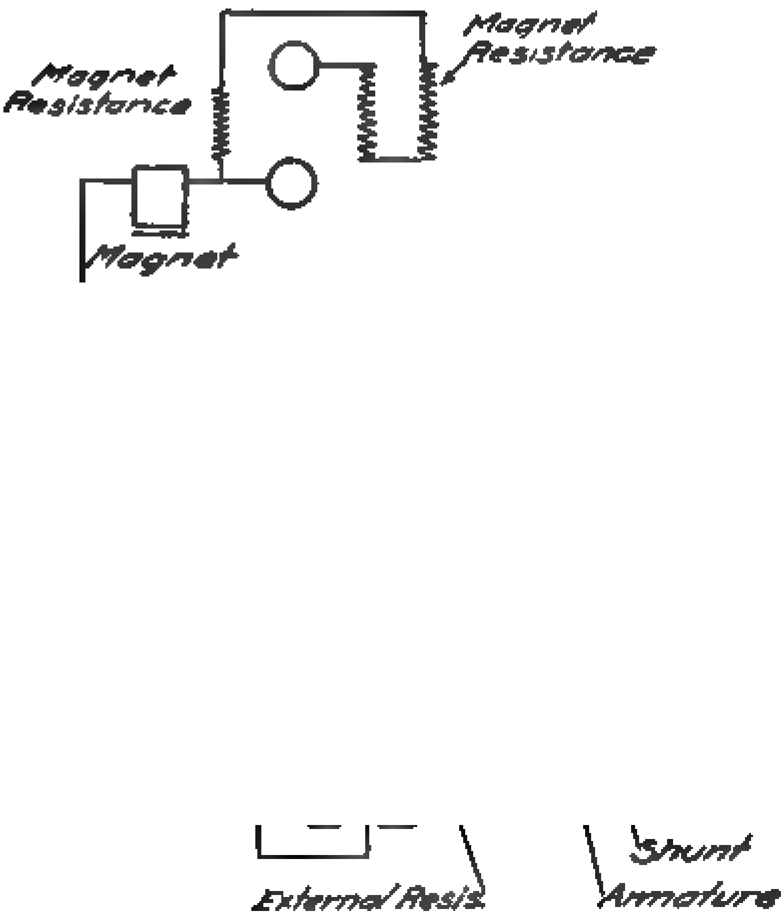


Fig. 443.—Internal Potential Circuit Connections of Thomson, Type CB-4, Continuous Current Rotating Standard, 110 and 550 Volts. Heating Key Down for Heating Position. Heating Key Up for Working Position.

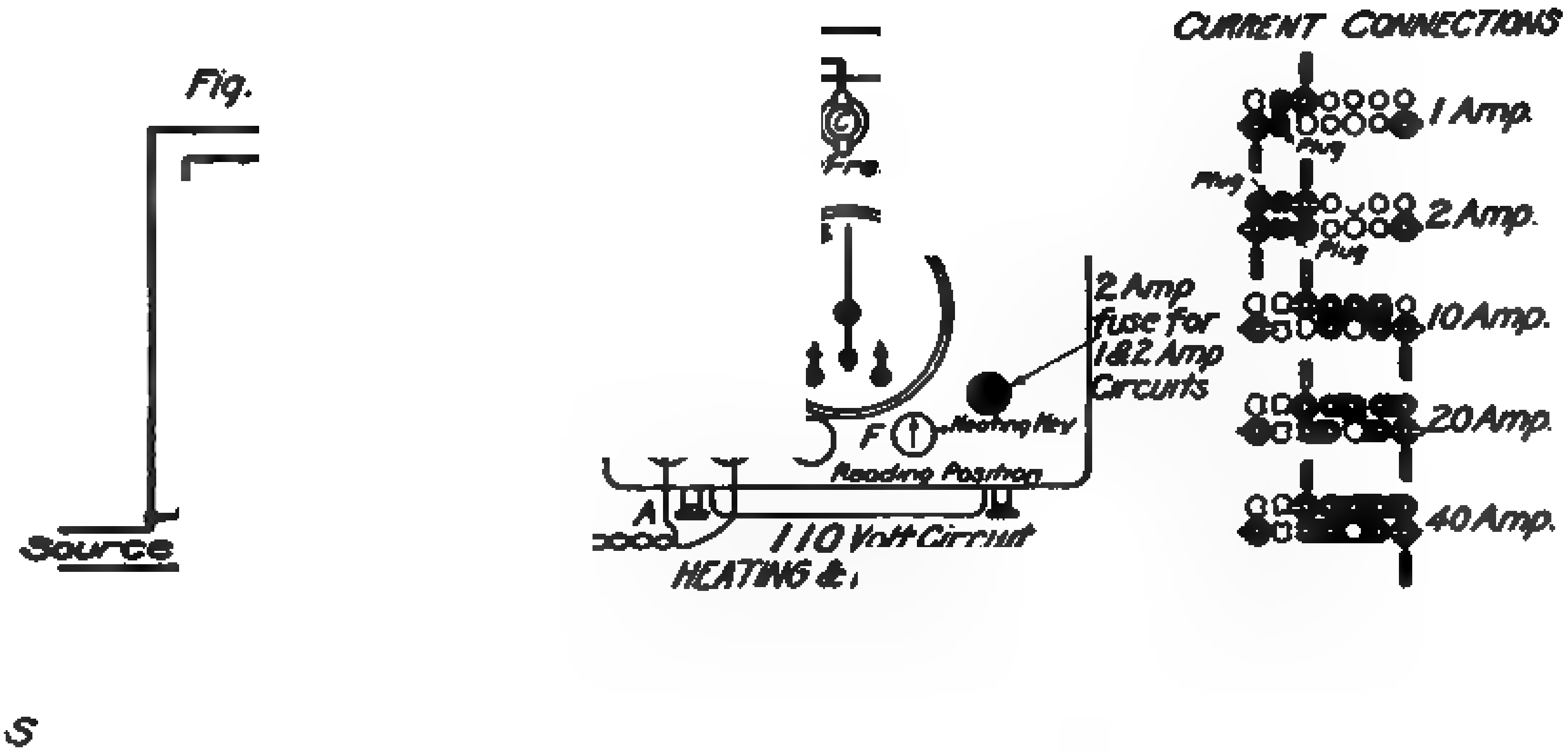


FIG. 444.—External Double-Voltage Connections of Thomson. Type CB-4. Continuous Current Rotating Standard, 1-2-10-20-40 Amperes, 110 and 220 Volts

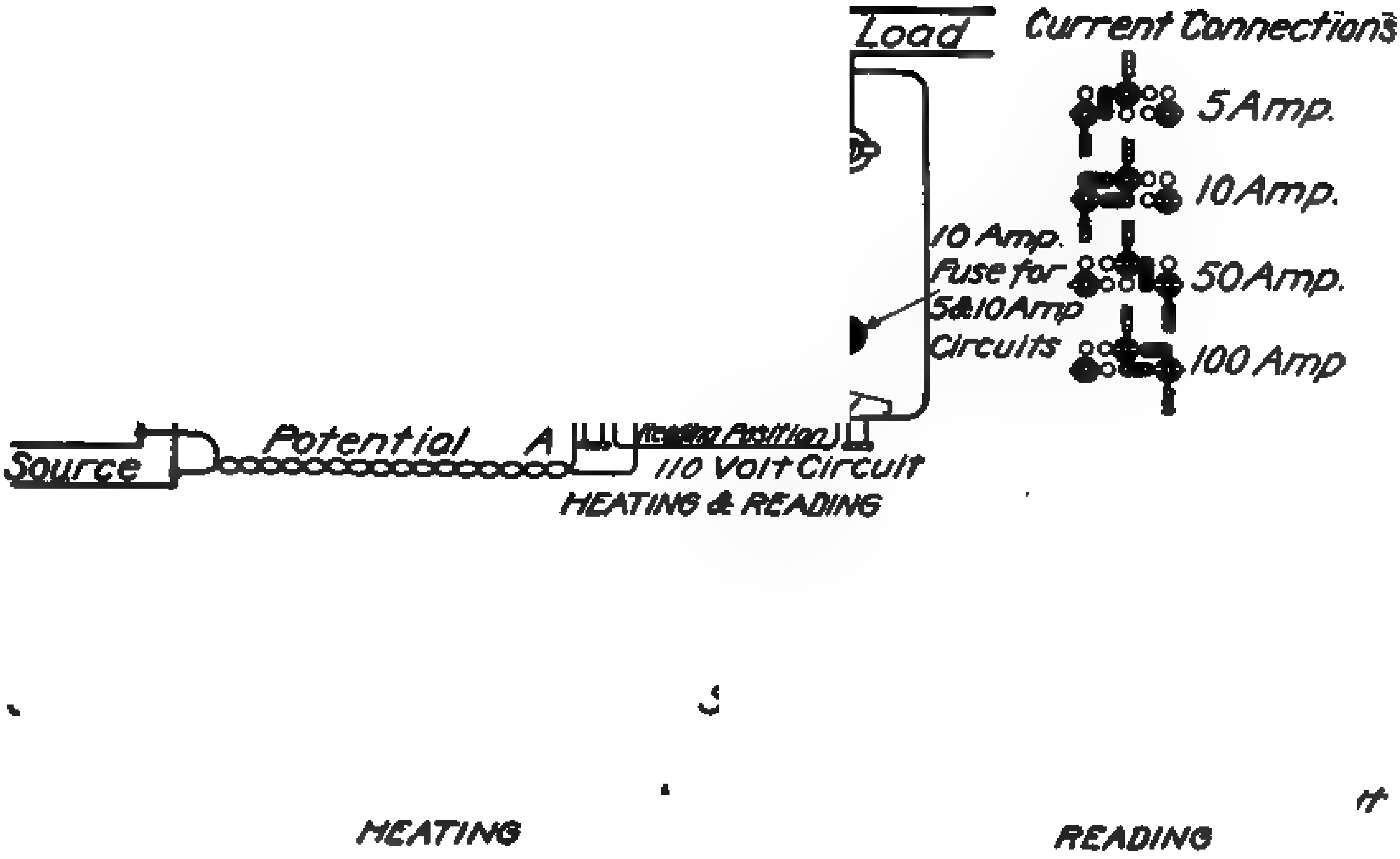


FIG. 445.—External Double-Voltage Connections for Thomson, Type CB-4, Continuous Current Rotating Standard, 5-10-50-100 Amperes, 110 and 220 Volts.

Fig. 446.—[illegible] Type CB-4, Continuous Current Rotating Standard, 1–2–10–20–40 Amperes, 110 Volts.

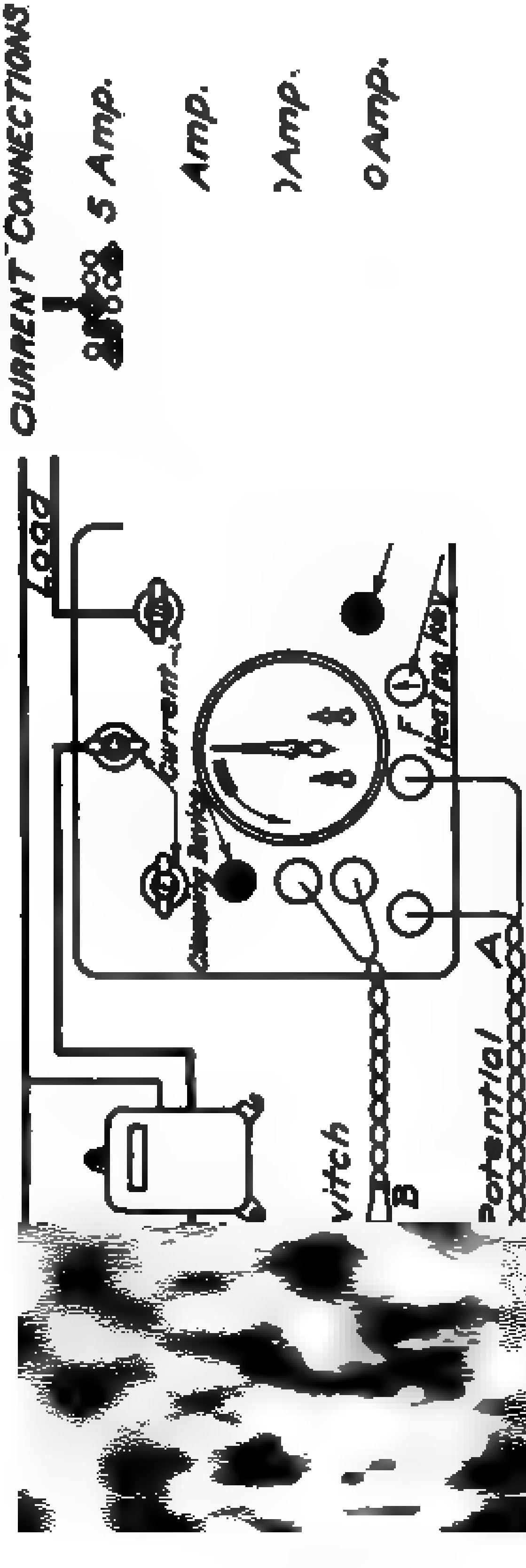


Fig. 447.—External Single-Voltage Connections of Thomson, Type CB-4, Continuous Current Rotating Standard, 5–10–50–100 Amperes, 110 Volts.

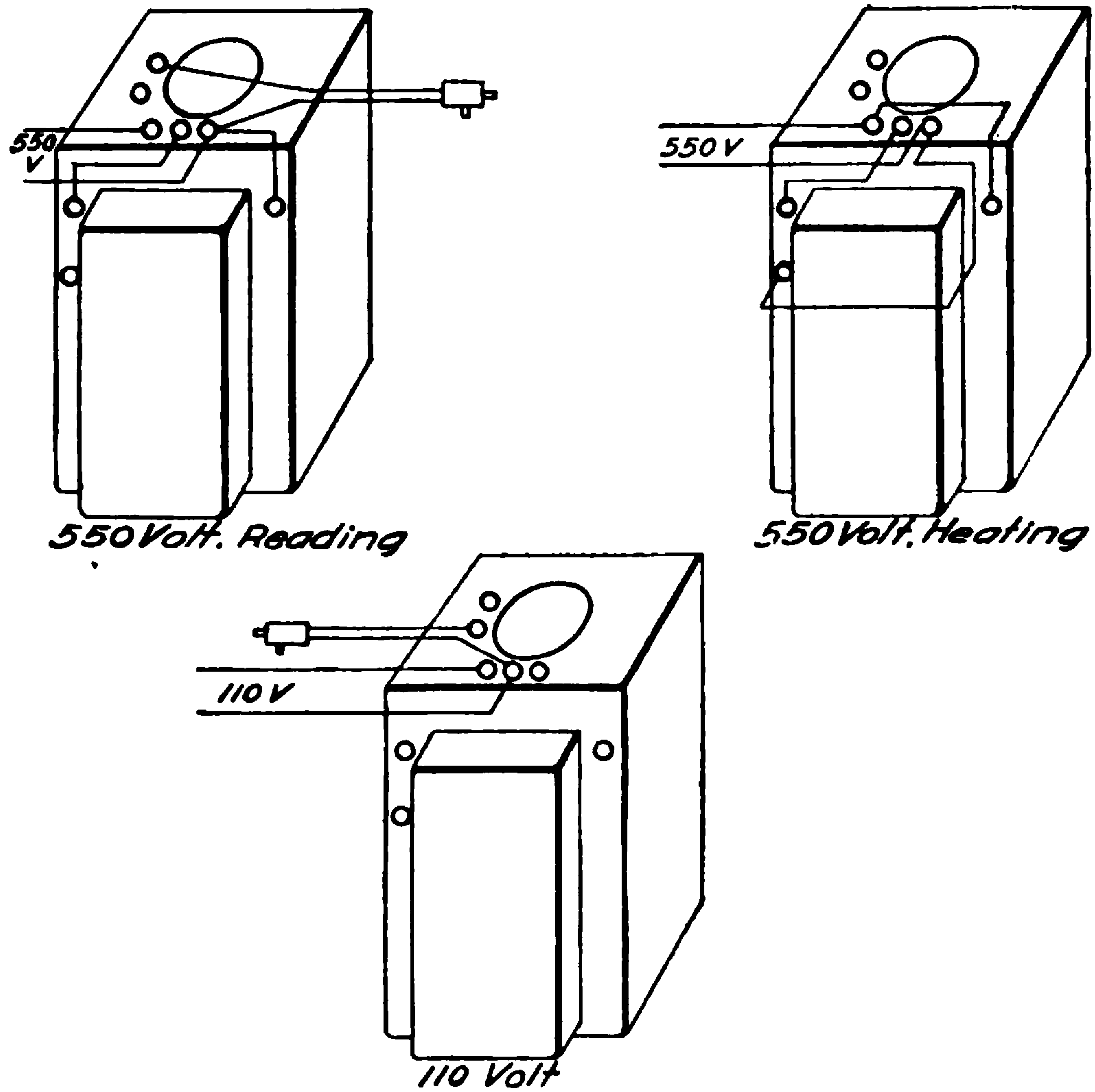


FIG. 448 —External Potential Circuit Connections of Thomson, Type CB-4, Continuous Current Rotating Standard, 110 and 550 volts.

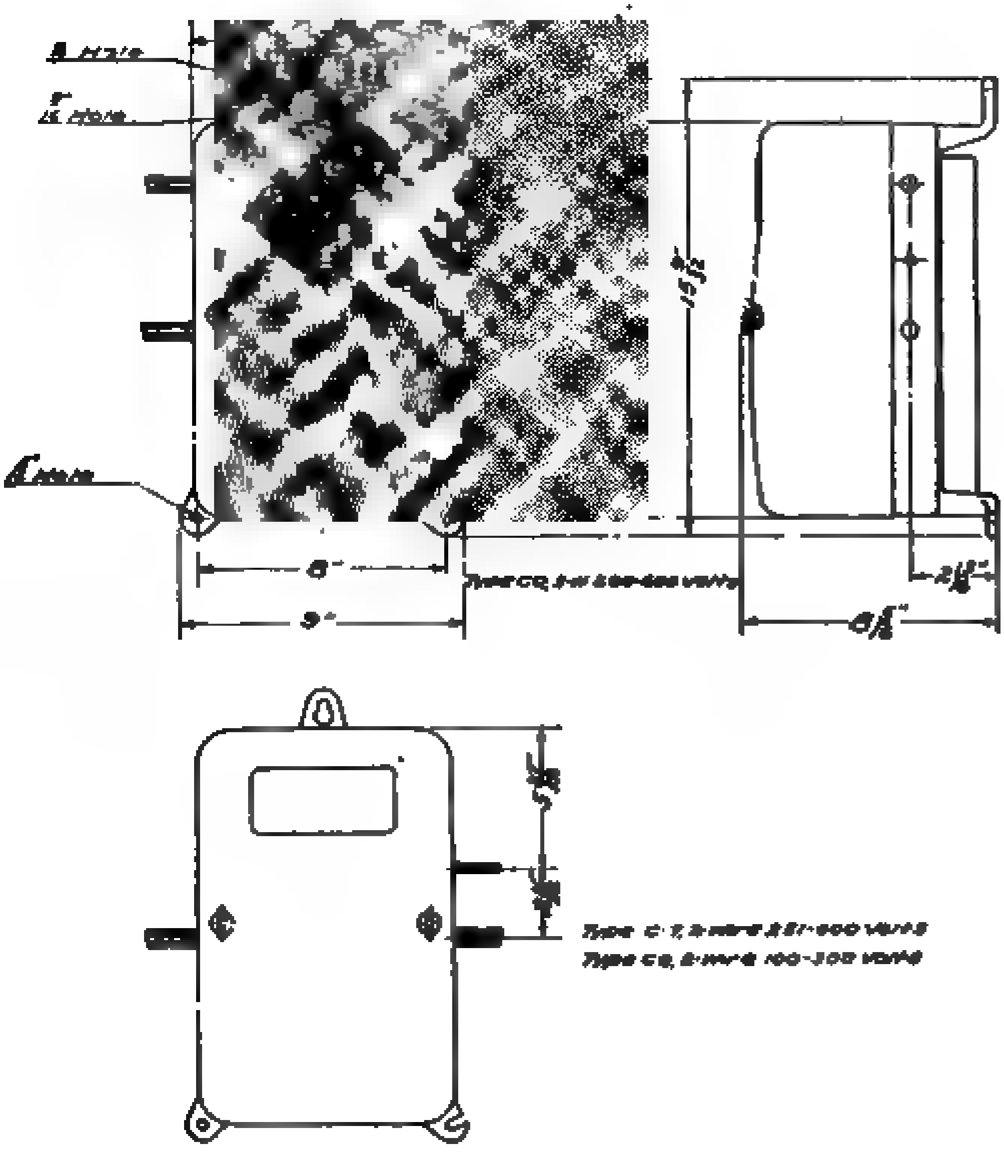


FIG. 449.—Dimensions of Thomson, Type C-7, Continuous Current Watt-hour Meters, 75 Amperes, 251–600 Volts, 2-wire. Type CQ Watt-hour Meters, 50 and 75 Amperes, 0–300 Volts, 2-wire, 200–600 Volts, 3-wire

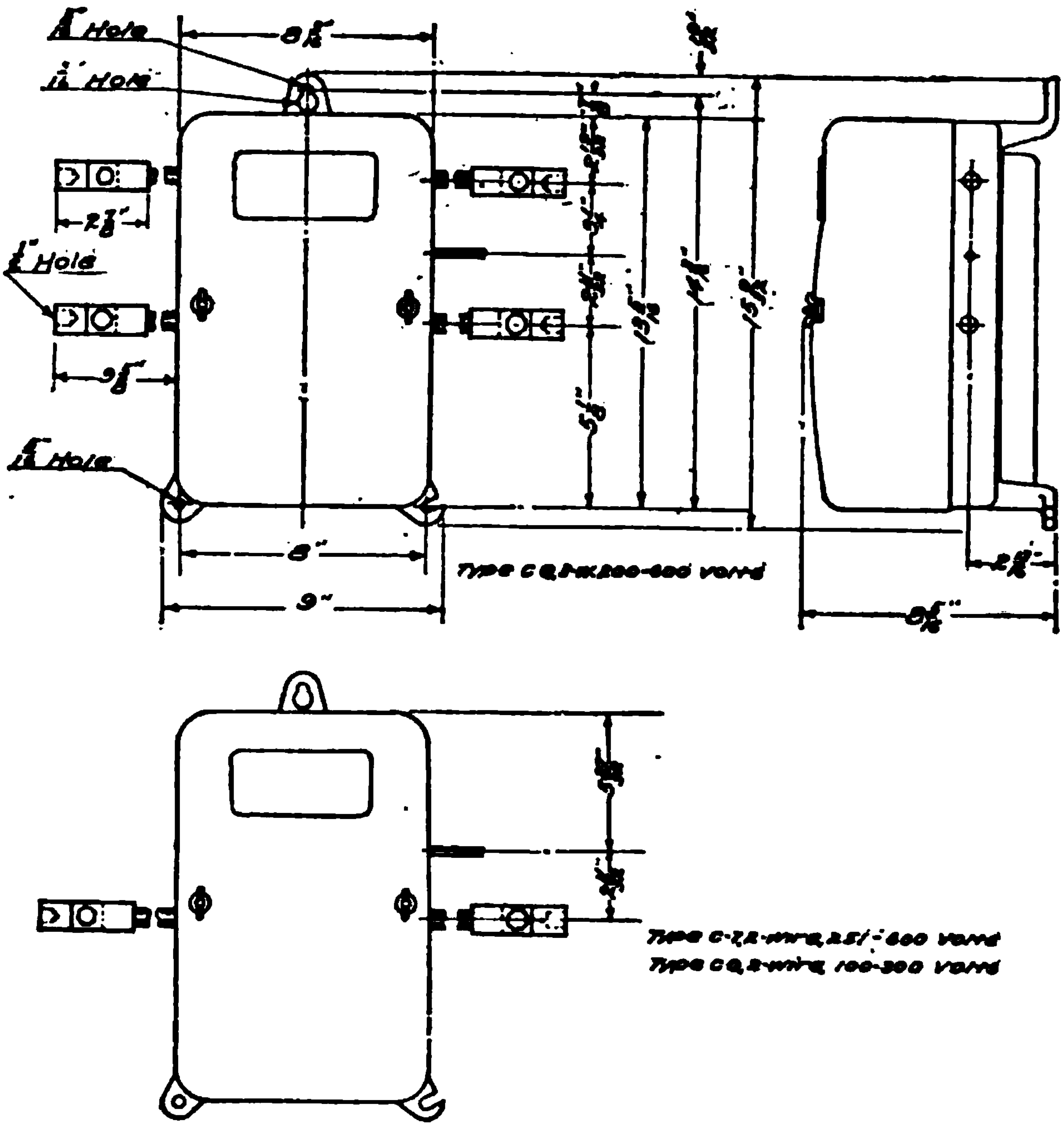


FIG. 450.—Dimensions of Thomson, Type C-7, Continuous Current Watt-hour Meters, 100 and 150 Amperes, 251–600 Volts, 2-wire. Type CQ Watt-hour Meters, 100 Amperes, 0–300 Volts, 2-wire, 200–600 Volts 3-wire.

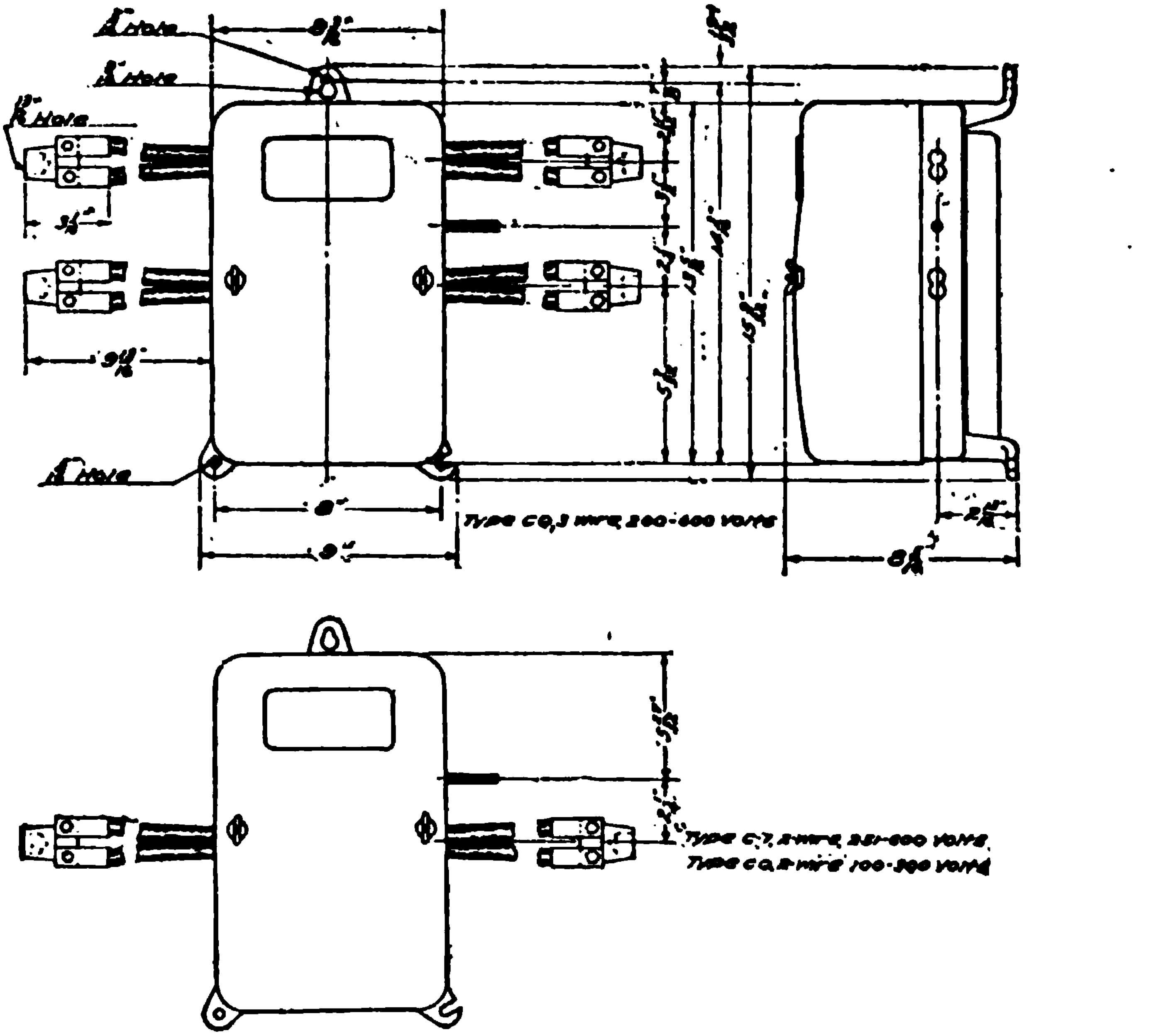


FIG. 451.—Dimensions of Thomson, Type C-7, Continuous Current Watt-hour Meters, 300 Amperes, 251–600 Volts, 2-wire. Type CQ Watt-hour Meters, 200 Amperes, 0–300 Volts, 2-wire, 200–600 Volts, 3-wire.

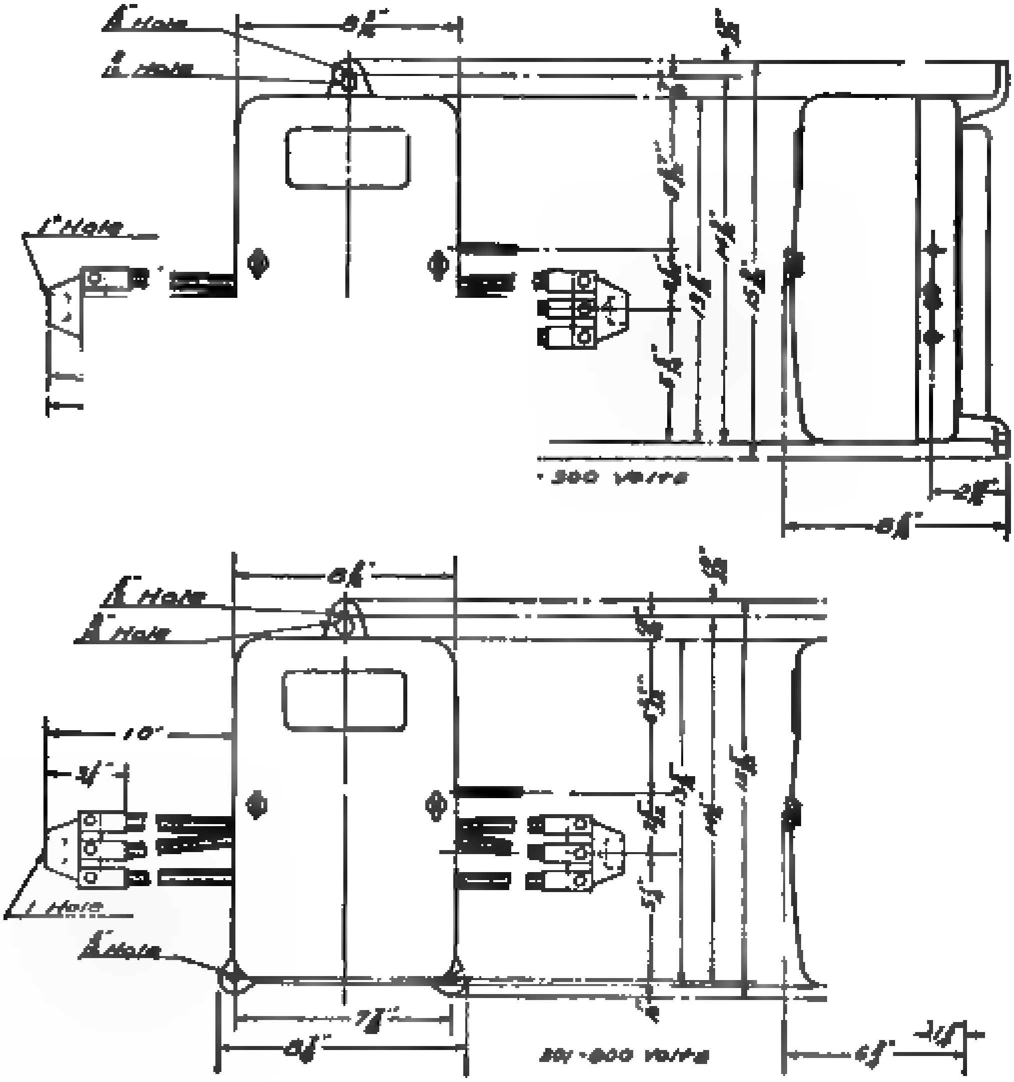


FIG 452 —Dimensions of Thomson, Type CQ. Continuous Current Watt-hour Meters, 400 Amperes, 0–800 Volts, 2-wire.

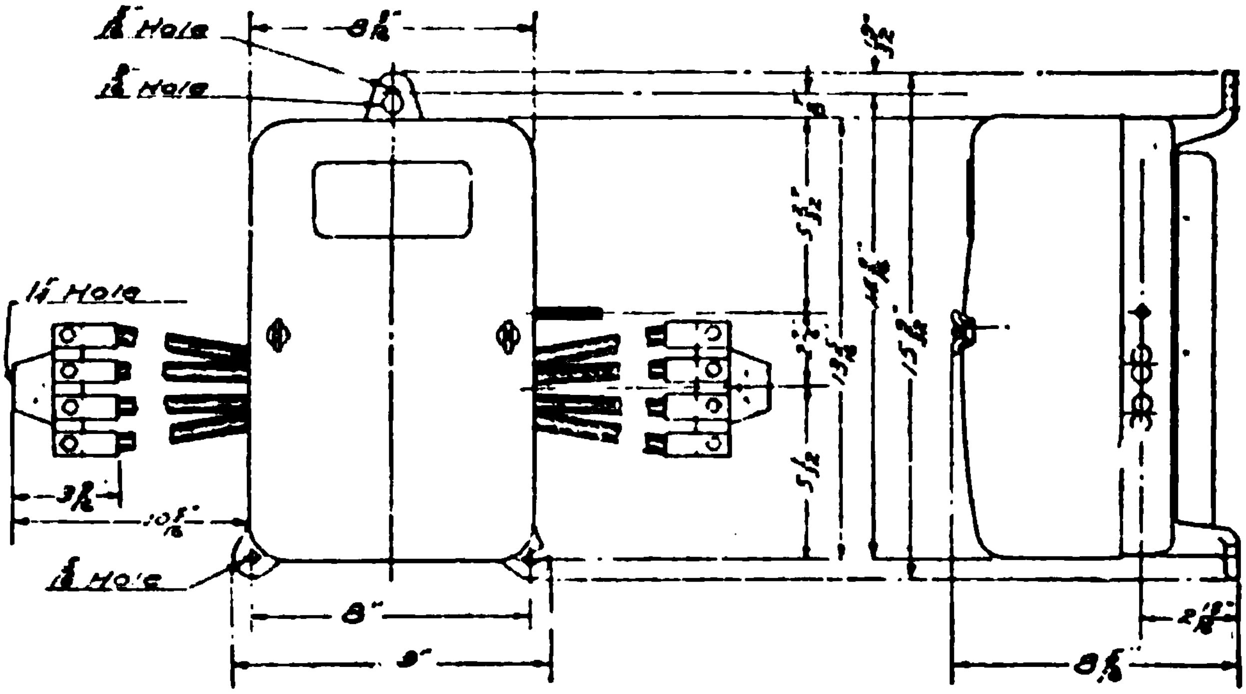


FIG. 453.—Dimensions of Thomson, Type C-7, Continuous Current Watt-hour Meters, 600 Amperes, 251–600 Volts, 2-wire.

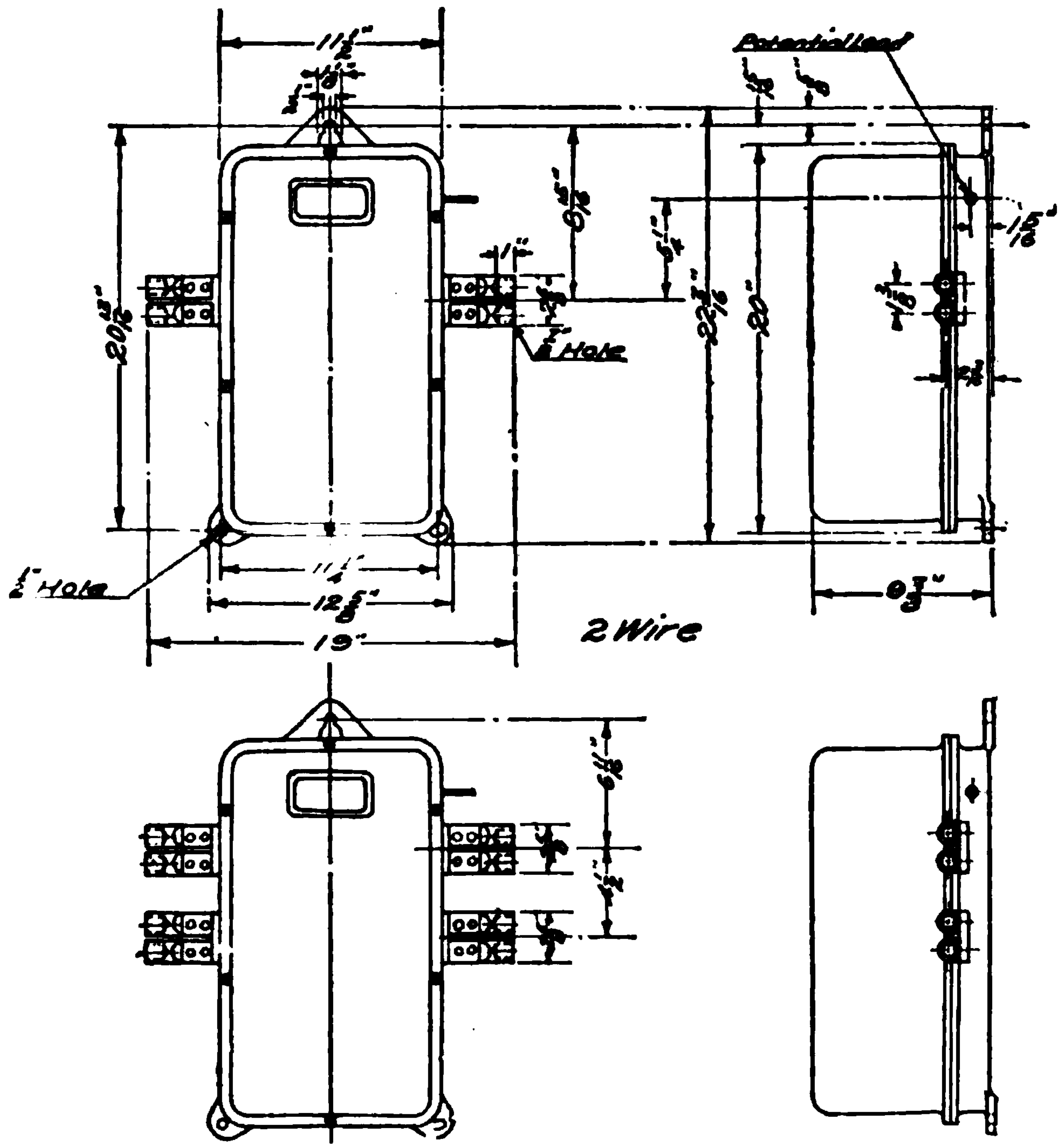


FIG. 454.—Dimensions of Thomson, Type CS-2, Continuous Current Watt-hour Meters, 400–800 Amperes, 0–750 Volts, 2-and 3-wire.

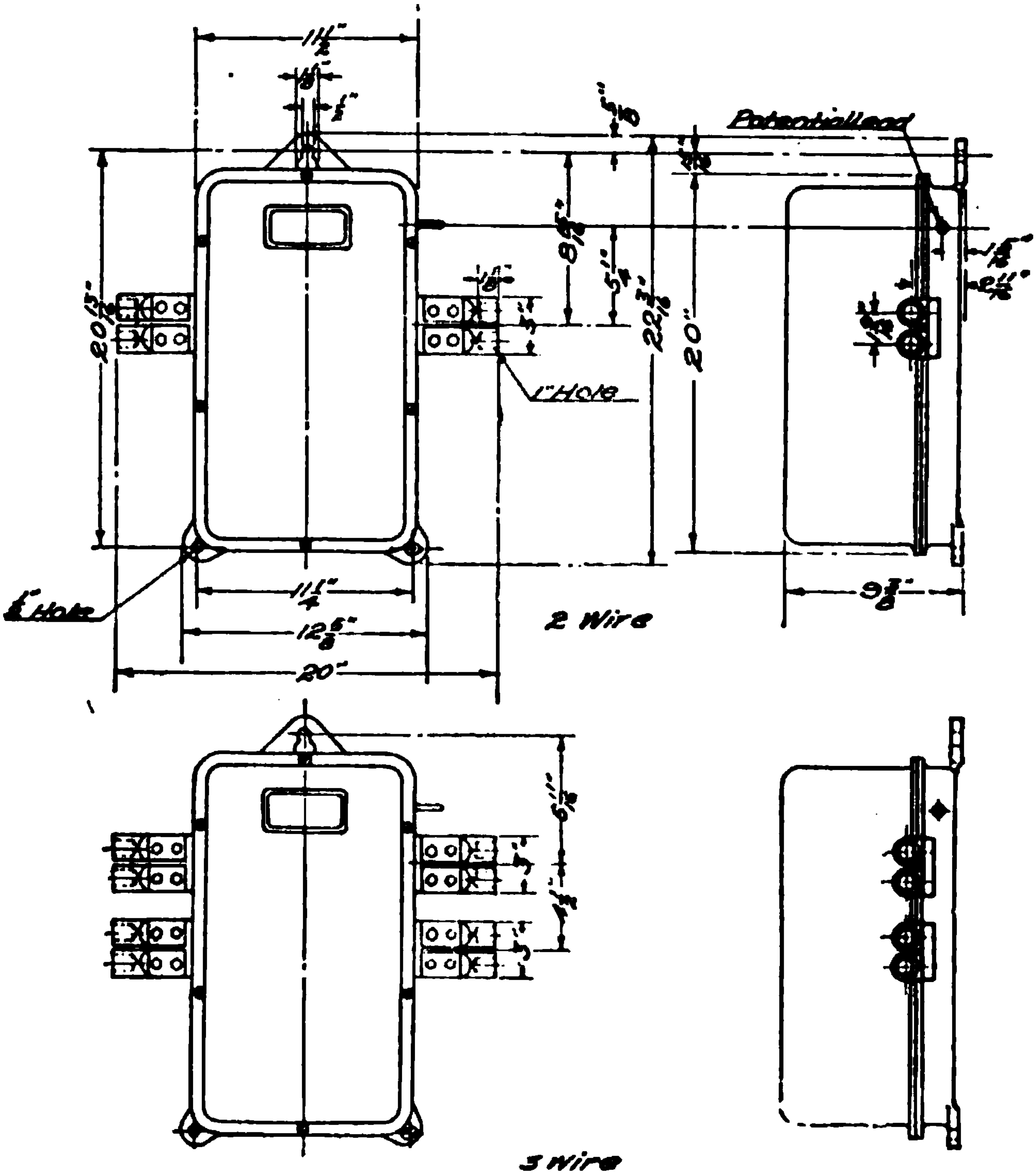


FIG. 455.—Dimensions of Thomson, Type CS-2, Continuous Current Watt-hour Meters, 1200–1500 Amperes, 0–750 Volts, 2- and 3-wire.

THOMSON, ALTERNATING CURRENT, INDUCTION WATT-HOUR METERS

In the **General Electric (Thomson) induction type of watt-hour meter for alternating current circuits** there is the usual combination of current and potential elements, establishing a rotating field which produces opposing fields by inducing current in a movable closed secondary, causing the rotation of same. It is, of course, obvious that the speed must be proportional to the wattage to be measured. In order for this to hold true, the combination of elements above referred to must produce a torque or turning moment directly proportional to the load or wattage. This is accomplished by causing the rotating element which is constructed of non-magnetic material to pass between the poles of permanent magnets which generate Foucault currents in it directly proportional to the speed.

The arrangement of the parts and connections of the coils of the Type I induction meter are shown diagrammatically in Fig. 456, which is a rear view. The figure is lettered for reference.

The function of the various coils and parts will be described.

D is an aluminum disk, mounted to rotate between the series and potential magnet poles, also between the poles of the permanent magnet brake.

SFC and SFC′ are the main series field coils wound in opposite directions on projecting iron cores. These coils produce the series field proportional to the current in the circuit.

IC is the impedance coil producing the field of the potential circuit proportional to the line e. m. f. This winding has a high reactance and is connected directly across the main circuit. The magnetic field produced lags nearly 90 degrees with respect to the e. m. f. impressed.

PC is a phasing coil consisting of a closed secondary or lagging winding, which produces a sufficient additional field to establish the exact 90 degree relation required.

AR is an adjustable resistance in series with the closed secondary winding to regulate the magnitude of the current.

LLA is the light load adjustment, a closed secondary of one turn of copper placed around the core of the potential coil and arranged to produce the necessary unbalancing of the field of the potential coil to compensate for friction.

L is a lever provided for adjusting the position of the closed secondary LLA with respect to the iron core.

T^1, T^2, T^3 and T^4 are the main terminals for connecting the meter in circuit.

BB is the bus-bar.

The phase relations of the magnetic fields produced by the various windings in the Type I meter are represented diagrammatically in the vector diagram, Fig. 457. In the diagram the phase relation and magni-

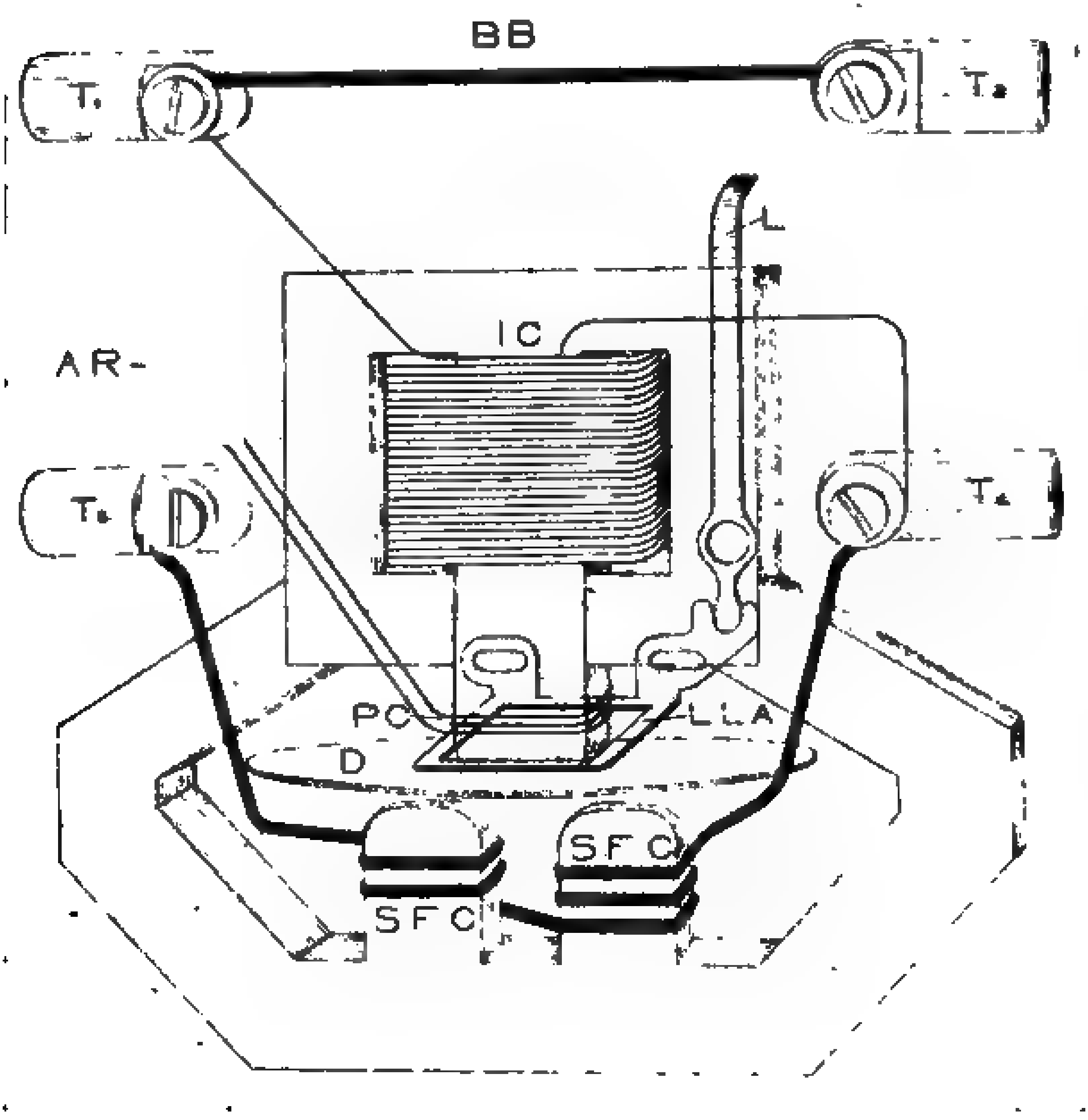


FIG 456.—Internal Arrangement of Thomson, Type I, Induction Watt-hour Meter.

tude of the components are magnified in order to make the description clear

OA represents the impressed e m f applied to the impedance coil, or potential coil, winding.

OB represents the current in the impedance coil, which lags nearly 90 degrees behind the impressed e. m. f., due to the reactance.

OE represents the e. m. f. induced in the closed secondary winding PC (Fig. 456), and is almost 180 degrees from OA.

OC represents the current in the closed secondary PC. This current is in phase with the induced e. m. f., OE, as the winding is practically non-inductive.

OD represents the magnitude and direction of the resultant magnetic field produced by the combined magnetizing effect of the current OB in the potential coil and the closed secondary current OC.

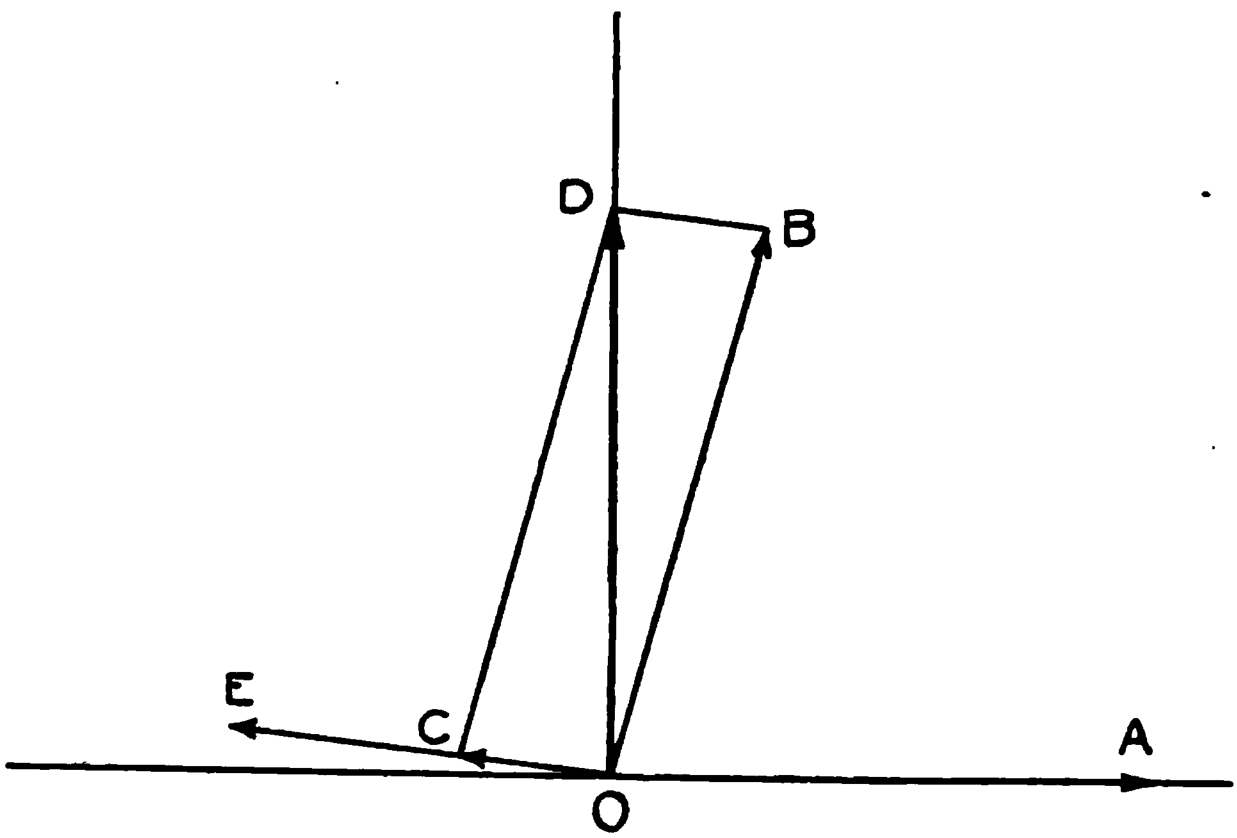


FIG. 457.—Vector Diagram of Phase Relations of Voltages in the Potential Circuit.

By means of the resistance AR (Fig. 456), the magnitude of the current OC may be either increased or decreased, thereby shifting the position of the resultant magnetic field OD until a phase relation of exactly 90 degrees is obtained between OA and OD.

The e. m. f. and current induced in the closed circuited armature, or disk, and light load adjusting, or compensating, coil are not shown in the diagram, as they are at all times practically in phase with the e. m. f. and current OE and OC.

When the resultant potential circuit field OD lies 90 degrees from OA, the meter will accurately register the energy on inductive and non-inductive loads.

Friction compensation is obtained by placing around the potential field core a movable copper turn, or closed secondary, LLA (Fig. 456).

The turn is made to fit closely over the lower end of the core of the potential field and has internal dimensions large enough to permit moving it horizontally either to the right or left.

The effect of the closed secondary turn is practically the same as the effect produced by the shading ring, or coil, on the pole of a single-phase induction motor.

Assuming that the secondary turn is not present, it is evident that with current in the potential circuit and no current in the series circuit, the field of the potential coil would be magnetically balanced. Introducing the secondary turn centrally with respect to the magnetic field would not alter the balanced condition.

Moving the turn in either direction would produce a slightly unsymmetrical condition of the field, which would result in a torque. This unbalanced condition is due to the reactive effects of the field of the secondary, which would then be greater on one side of the potential circuit field pole. This produces the effect of a slight rotating field. The turn may be adjusted to such a position that the unbalanced field will produce just sufficient torque to overcome the friction of the moving element.

The Thomson, alternating current, induction watt-hour meters are classed as High Torque, Types I, I-8, IP-2, IP-3, IP-4, IS, IS-2, IS-3, I-10, IB, IB-2, IB-3, IB-4, D-3, D-4, DS-2, DS-3, DS-4 and DS-5.

The I types include the single-phase or balanced polyphase forms, and the D types represent the universal polyphase forms.

The induction watt-hour meter is provided with a **light load adjustment** which can be used to correct for variations in local conditions. The device consists of a movable sector located between the poles of an electromagnet.

Standing so that the device is brought directly between the observer and the shaft of the moving element of the meter, moving the sector toward the right increases the speed at light loads; moving it toward the left causes the meter to run more slowly at light loads and also tends to prevent creeping. If the sector is moved too far, so as to pass beyond the field of the electromagnet, its effects will be correspondingly diminished. The movement affects only the light load accuracy of the meter and has no effect upon the full load; therefore, it is not necessary to recalibrate the watt-hour meter after making this adjustment.

Owing to its lightness, there may be a tendency under certain conditions for the moving element of these watt-hour meters to creep on no load, even when the light load adjustment is properly set. To counteract this in High Torque and earlier types an iron wire is

fastened to the disk adjacent to the hub. This wire should not be moved unless it is found that creeping exists. The wire should then be slightly inclined radially away from the shaft. Care must be exercised in doing this, as too much of a movement will prevent the meter starting at sufficiently light load. Moving the wire toward the shaft will tend to make the meter run faster on light load. On High Torque watt-hour meters this iron wire is placed around the hub parallel with the disk and may be bent to or from the shaft.

Fig. 458.—Thomson, Type DP-2, High-Torque, Single-phase, Induction Watt-hour Meter

The adjustment when properly made will not in any way interfere with the running of the watt-hour meter, but will prevent creeping on no load.

In the types I and D, the tendency to creep is counteracted by two small holes in the disk.

The following is given as an explanation of the **significance of the letters used in designating these types** of Thomson, alternating current, induction watt-hour meters:

High Torque—House service, single-phase type. Replaced C-4, now obsolete. Superseded by Type I (Fig 458).

Type I —House service, single-phase type.

Type I-8 —Similar to Type I, except that terminals are in separate compartment

Type IP-2 —Prepayment type; combination of separate prepayment attachment and watt-hour meter.

Type IP-3 —Superseded IP-2, with radical change of design. Prepayment feature and watt-hour meter in the same case.

Type IP-4 —Superseded IP-3, with change in operating knob and other details.
Type I-10 —Low capacity, house service, single-phase type.
Type IS —Switchboard, single-phase type.

Internal View of Thomson, Type I, High-Torque, Single-phase, Induction Watt-hour Meter.

External View of Thomson, Rectangular Pattern, Type DP-2, Polyphase, Induction Watt-hour Meter

Fig. 459.

Type IS-2 —Same as IS, except mechanical details and damping mechanism.
Type IS-3 —Same as IS-2, except that it has glass cover.
Type DF-2 —Polyphase rectangular pattern (Fig. 459). Superseded by Type D-3.
Type D-3 —House service, polyphase type.
Type D-4 —Similar to D-3, except separate terminal compartment.

Type DS-2 —Switchboard, polyphase type, with cast metal cover.
Type DS-3 —Same as DS-2, except that it has glass cover.
Type DS-4 —Supersedes Type DS-2, with slight difference in location of electrical elements.
Type DS-5 —Supersedes Type DS-3, with slight difference in location of electrical elements.
Type IB —Portable rotating standard type, with characteristics similar to Type IS in some respects.
Type IB-2 —Supersedes Type IB, with changes in damping system.
Type IB-3 —Similar to Type IB-2, except that range was extended and details changed.
Type IB-4 —Similar to Type IB-3, except minor details.

The Type I Thomson watt-hour meter was designed for house service for use upon single-phase, two- or three-wire, or balanced three-phase circuits. It is built self-contained in capacities of 3, 5, 10, 15, 25, 50, 75, 100, 150, 200 and 300 amperes, 0 to 650 volts, 25 cycles and above, for two-wire and balanced three-phase circuits; and 3, 5, 10, 15, 25, 50, 75, 100 and 150 amperes, 200 to 650 volts, 25 cycles and above, for three-wire circuits. For three-wire circuits above 150 amperes, transformers are employed (Fig. 460).

This type of watt-hour meter can be furnished double lagged for 60 cycles and a higher frequency. By changing the connections inside of the meter, it may be used for either frequency for which it is rated without recalibration.

This meter is finished in dull black japan, the cover being provided with glass windows for observing the operation of the moving element and for reading the meter registers. When so desired a molded glass cover can be furnished.

The leading-in wires enter into the binding posts located at the sides of the meter.

This type was produced in December, 1903.

The Type I-8 Thomson watt-hour meter, like the Type I, was designed for house service, and is built in capacities of 3, 5, 10, 15, 25, 50 and 75 amperes, 0 to 650 volts, 25 cycles and above, for use upon two- or three-wire single-phase, and balanced three-phase circuits.

This watt-hour meter is essentially the same as the Type I, except that the terminals are located in a separate compartment at the bottom of the watt-hour meter, permitting the connection being made without removing the cover of the meter proper (Fig. 461).

For gaining access to the jewel screw when watt-hour meter is

Internal View of Thomson, Type I High-Torque, Single-phase, Induction Watt-hour Meter.

External View of Thomson, Type I, High-Torque, Single-phase, Induction Watt-hour Meter.

FIG. 460.

sealed, the meter cover is drilled directly below the jewel screw and by removing the terminal cover the jewel may be readily removed for inspection or replacement. Replacing the terminal cover prevents further access to the jewel screw.

This watt-hour meter element is electrically identical with the Type I, and same data applies.

This type was produced in March, 1906.

The Type IP-2 Thomson prepayment watt-hour meter was a combination of a separate prepayment attachment and watt-hour meter, the prepayment mechanism which is of the well-known "Wood"

FIG. 461.—External View of Thomson, Type I-8, High-Torque, Single-phase, Induction Watt-hour Meter.

construction, being mounted on the top of the watt-hour meter proper, the gearing and actuating mechanism being directly connected to the recording mechanism of the meter.

This type of watt-hour meter was built in capacities of 3, 5, 10, 15 and 25 amperes, 100 to 250 volts, 25 cycles and above, for two-wire circuits, and 200 to 250 volts, 25 cycles and above, for three-wire circuits, and was adapted for either a ten or twenty-five cent coin.

This meter was furnished in black japan, the cover, as in the other forms of induction watt-hour meters, being provided with register and moving element windows.

This type was produced in September, 1905.

The Type IP-3 Thomson prepayment watt-hour meter was a radi-

cal redesign, and superseded the Type IP-2 watt-hour meter. The same improved design and construction of mechanism are incorporated in the CP-3 prepayment meter.

The watt-hour meter and prepayment mechanism are housed in the same case, and are accessible for adjustment by removing the meter cover. The coin box may be emptied by the collector without removing the meter cover, and, conversely, removal of the meter cover does not permit of access to the coin box.

For convenience in reading the register and noting the number of coins to consumer's credit, the coin register and watt-hour meter register dial plate are combined, the hand indicating the coins to credit being directly above the dials of the dial plate.

Like the IP-2 meter, the Type IP-3 is built in capacities of 3, 5, 10, 15 and 25 ampères, 100 to 250 volts, 25 cycles and above, for two-wire circuits, and 200 to 250 volts for three-wire circuits.

This type was produced in September, 1908.

The Type IP-4 Thomson prepayment watt-hour meter supersedes the Type IP-3, and is the same throughout, except that the operating knob is now fastened in the cover and operates the prepayment mechanism through a driving dog, thus preventing injury of the mechanism by any strain on the knob (Fig. 462).

The Type IP-4 meter element is electrically identical with the Type I, and same data applies.

This type was produced in October, 1908.

The Type I-10 Thomson watt-hour meter was designed to meet the demand for a low capacity, single-phase, two- or three-wire house meter.

This type of watt-hour meter is different in construction and appearance from any type of induction watt-hour meter previously put on the market by the General Electric Company (Fig. 463).

The electrical properties are little different from the Type I watt-hour meter.

The **full load adjustment** is accomplished by shunting the flux of the magnet about the disk instead of moving the magnets, as in the Type I. The dial face has three dials. This watt-hour meter is circular in form, the cover screws into place, similar to the top of a fruit jar, and it has a molded terminal block at the bottom of the meter base into which the leading-in wires pass. The jewel and pivot are removable and the friction compensation is adjustable to allow for wear. The dials read in kilowatt-hours, and the dial face is of dull finish porcelain. The meter back and cover are finished in dull black japan.

This type was produced in 1910.

The Type IS Thomson watt-hour meter was designed for switchboard use on single-phase, two- and three-wire circuits and balanced three-phase circuits. In this type the drag magnets are not movable. Full load adjustment is accomplished by shunting more or less of the magnetic lines of force.

Fig. 462.—Thomson, Type IP-4, Prepayment, Single-phase, Induction Watt-hour Meter.

In order to do this, the meter has four angle irons fastened at the front of the magnets. Moving these irons nearer together will make the meter run faster, while moving them apart will make it run more slowly.

A small rectangular conductor located below the potential coil provides for light load adjustment.

The movement of this conductor is controlled by a lever at the upper left-hand side of the meter. To change the adjustment, loosen

Fig. 463.—Thomson, Type I-10, Single-phase, Induction Watt-hour Meter.

the screw and move the lever to the right or left, as required. Moving the lever to the right increases the speed on light load, while a movement to the left decreases it.

Changing the position of this adjusting device affects only the light load of the meter; it is, therefore, unnecessary to recalibrate on full load after it has been moved.

This type was produced in October, 1903.

The Types IS-2 and IS-3 Thomson watt-hour meters superseded the Type IS watt-hour meter.

The Type IS-2 is the same as the Type IS, with the exception of changes in the mechanical construction and damping mechanism. The damping mechanism is identical with that of the Type I watt-

Fig. 464.—Thomson, Type IS-2, Single-phase, Induction Watt-hour Meter.

Fig. 465.—Thomson, Type IS-3, Single-phase, Induction Watt-hour Meter.

hour meter, and the moving element is the same as the Type IS. The terminals and frames have been modified. The cover is of cast iron.

This type was produced in May, 1905 (Fig. 464).

The Type IS-3 meter is identical with the IS-2 except for the cover, which is of glass (Fig. 465).

This type was produced in January, 1906.

The Type D-3 Thomson watt-hour meter is designed for house service, for use upon two-phase, three-phase and monocyclic circuits of balanced or unbalanced loads. It is built self-contained, in capacities of 3, 5, 10, 15, 25, 50, 75, 100 and 150 amperes, 0 to 650 volts, 25 cycles and above, for use upon four-wire, two-phase, three-wire, two- and three-phase and monocyclic circuits, and in capacities of 3, 5, 10, 15, 25, 50 and 75 amperes, 0 to 650 volts, 25 cycles and above, for use upon four-wire, three-phase circuits (Figs. 466 and 467).

As in the case of Type I watt-hour meters, this type of meter

FIG. 466.—External View of Thomson, Type D-3, Polyphase, Induction Watt-hour Meter.

FIG. 467.—Internal View of Thomson, Type D-3, Polyphase, Induction Watt-hour Meter.

may be used for switchboard service with good results, where a back-connected meter is not desired.

This meter is finished in dull black japan, the cover being provided with glass windows for observing the operation of the moving element and for reading the meter dials.

The leading-in wires enter into binding posts located at the sides of the meter.

Fig. 468.—Thomson, Type D-4, Polyphase, Induction Watt-hour Meter. Separate Sealed Terminal Type.

The Type D-4 Thomson watt-hour meter, like the Type D-3, is designed for house service and is built in capacities of 3, 5, 10, 15, 25, 50 and 75 amperes, 0 to 650 volts, 25 cycles and above, for use upon three-wire, two- and three-phase and monocyclic, four-wire, two- and three-phase circuits. This type of watt-hour meter is in general similar to the Type D-3 except that the terminals are located in a separate compartment at either side of the meter back, permitting the connections being made without removing the cover of the meter proper (Fig. 468).

This type was produced in March, 1906.

The Types DS-2 and DS-3 Thomson watt-hour meters were designed for switchboard service for use upon two-phase, three-phase or monocyclic circuits of balanced or unbalanced loads. They are built self-con-

tained in capacities of 3, 5, 10, 15, 25, 50, 75, 100 and 150 amperes, 0 to 650 volts, 25 cycles and above, for use upon four-wire two-phase, three-wire, two- and three-phase and monocyclic circuits, and in capacities of 3, 5, 10, 15, 25, 50 and 75 amperes, 0 to 650 volts, 25 cycles and above for use upon four-wire three-phase circuits.

The former type of watt-hour meter has a cast metal cover, surface of which is pebbled and provided with glass windows for observing the operation of the moving element and for reading the dials (Fig. 469).

The latter type of watt-hour meter has a rectangular glass cover (Fig. 470).

The current and potential circuits of these meters are independent of

FIG. 469.—Thomson, Type DS-2, Polyphase, Induction Watt-hour Meter.

FIG. 470.—Thomson, Type DS-3, Polyphase, Induction Watt-hour Meter.

each other, hence, these meters are interchangeable for use with, or without transformers.

The types DS-2 and DS-3 meters are finished in dull black, the raised portion of the Type DS-2 meter being finished in polished copper.

Type DS-2 was produced in July, 1906, and Type DS-3 in May, 1906.

The Types DS-4 and DS-5 Thomson watt-hour meters superseded respectively the Types DS-2 and DS-3 (Figs. 471 and 472).

The same general characteristics are maintained in the Types DS-4 and DS-5 watt-hour meters as in the Types DS-2 and DS-3, the slight difference being in the location of the electrical elements.

Electrical data the same as for Type D-3.

Types D-4 and D-5 were produced in August, 1908.

The Type IB Thomson portable, rotating standard represents the first induction portable rotating standard manufactured by the General Electric Company.

FIG. 471.—Thomson, Type DS-4, Polyphase, Induction Watt-hour Meter.

This type of watt-hour meter was built in some respects similar to the Type IS meter, the magnetic element and damping system of the latter meter being embodied.

In the Type IB-2 Thomson portable, rotating standard, the use of the

FIG. 472.—External View of Thomson, Type DS-3, Polyphase, Induction Watt-hour Meter.

damping system of the IS meter was discontinued and the damping system of the Type I meter adopted. Modifications in general were made to adapt the meter to the requirements of the operating companies.

The Types IB and IB-2 meters were built with capacities of 1, 10 and 20 amperes.

Upon the designing of the Type IB-3 Thomson portable rotating standard, the range was increased, this type of watt-hour meter being

FIG. 473 — External View of Thomson, Type IB-4, High-Torque, Single-phase, Induction Rotating Standard, High Capacity.

built in capacities of 1, 10 and 20 amperes, and 1, 5, 10, 50 and 100 amperes. In previous types of meter, the one ampere circuit was protected by a fuse plug of the type commonly used in wiring. In the Type IB-2 meters, a new design of fuse plug was incorporated, which permitted of the renewing of the fuse without replacing the entire plug.

In low capacity meters, i. e., 1, 10 and 20 amperes, the one ampere rcuit is protected by a fuse, and in the high capacity meters, i. e., 1, 5,

10, 50 and 100 amperes, the 1 and 10 ampere circuits are protected by fuses.

The Type IB-4 Thomson portable, rotating standard differs in minor mechanical details only from the Type IB-3, having the same electrical characteristics (Figs 473 to 477).

Data on performance of Types I, I-8 and IP-4 watt-hour meters are given below:

Speed of moving element at full load	30	rev. per min.
Torque at 110 volts	77	mm-g.
Weight of moving element	33	grammes

FIG. 474.—Internal View of Thomson, Type IB-4, High-Torque, Single-phase, Induction Rotating Standard, Low Capacity.

Ratio of torque to weight	2.33
Watt loss in potential circuit, 110 volts	3
Watt loss in series circuit	0.86

Similar data on Type I-10 watt-hour meters follow:

Speed of moving element at full load	36	rev. per min.
Torque at 110 volts	46.6	mm-g.
Weight of moving element	26.24	grammes
Ratio of torque to weight	1.77	
Watt loss in potential circuit, 110 volts	2.5	
Watt loss in series circuit, full load	0.98	

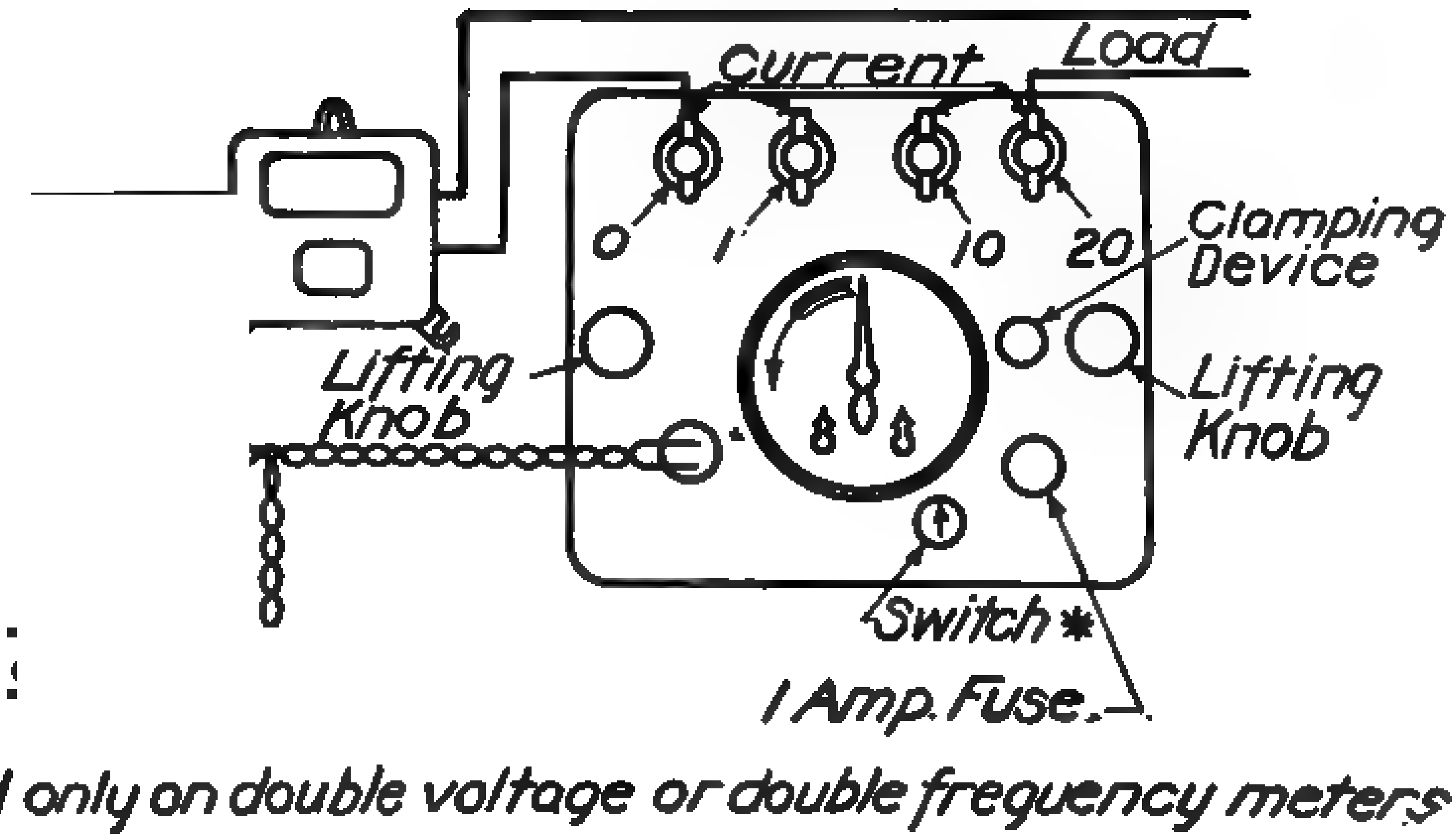
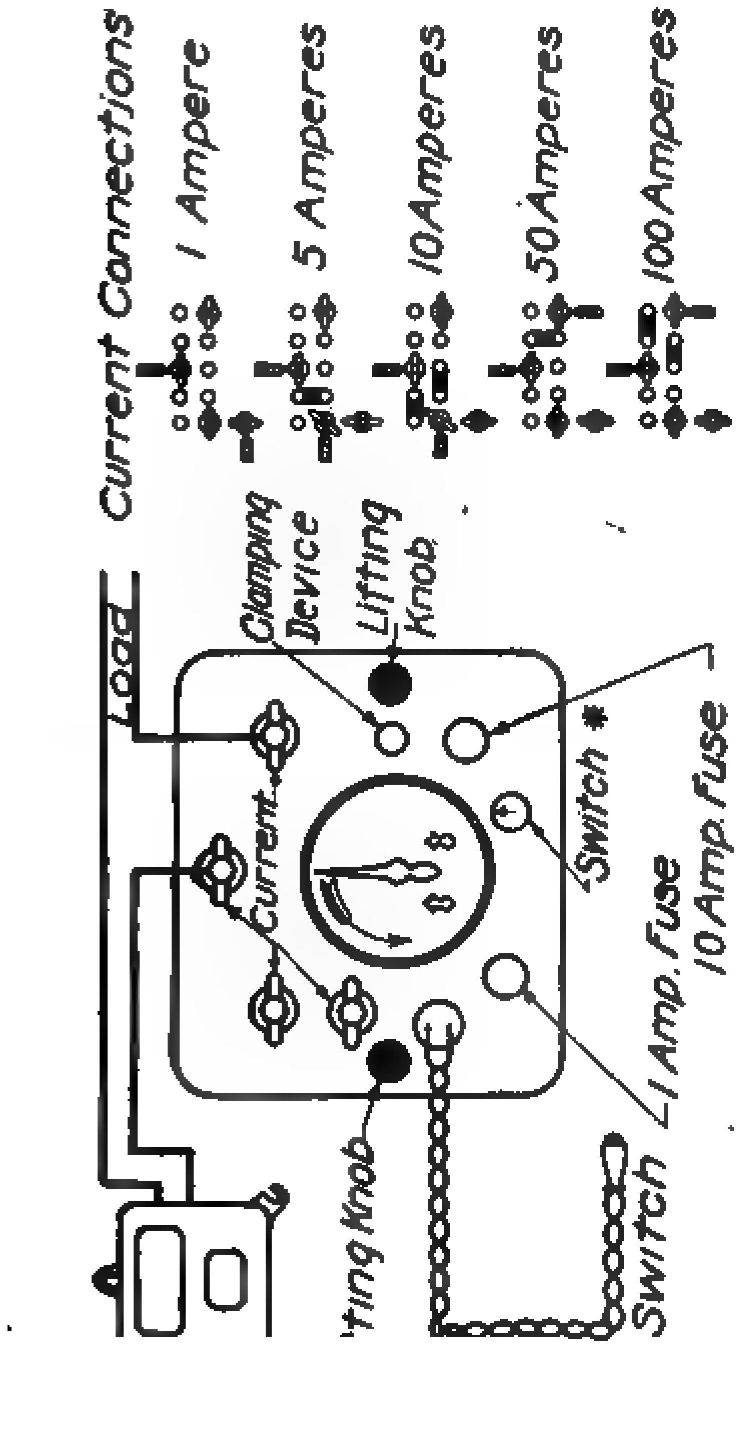


FIG. 475.—External Connections for Thomson, Type IB-4, Single-phase, Induction Rotating Standard, 1–10–20 Amperes, 110–220 Volts-Double Voltage.



* Used only on double voltage double frequency meters

FIG 476 —External Connections for Thomson, Type IB-4, Single phase, Induction Rotating Standard, 1-5-10-50-100 Amperes, 110-220 Volts, Double Voltage.

Similar data on Types IS, IS-2 and IS-3 watt-hour meters follow:

Speed of moving element at full load..............30 rev. per min.
Torque at full load, 110 volt, 60 cycles.............77 mm-g.
Weight of moving element..........................29 grammes
Ratio of torque to weight.......................... 2.65
Watt loss in potential circuit, 100 volts, 60 cycles...... 1.25
Watt loss in current circuit, full load, 10 amperes..... 1.0

FIG. 477.—Internal Connections of Thomson, Types IB-2 and IB-4, Single-phase, Induction Rotating Standard, 1–5–10–50–100 Amperes, Single and Double Voltage, or Double Frequency.

Similar data on Types D-3, D-4 and D-5 watt-hour meters follow:

Speed of moving element at full load......30 rev. per min. (Approx.)
Torque at full load, 110 volt, 60 cycles.....150 mm-g.
Weight of moving element................69 grammes
Ratio of torque to weight................. 2.23
Watt loss in potential circuit, 110 volt, 60 cycles, 2 elements.................. 2.5
Watt loss in current circuit, full load.... .. 1.25 at 5 amp. to 14.25 at 150 amp.

Connections for Double Lag Adjustment and Separate Potential Testing

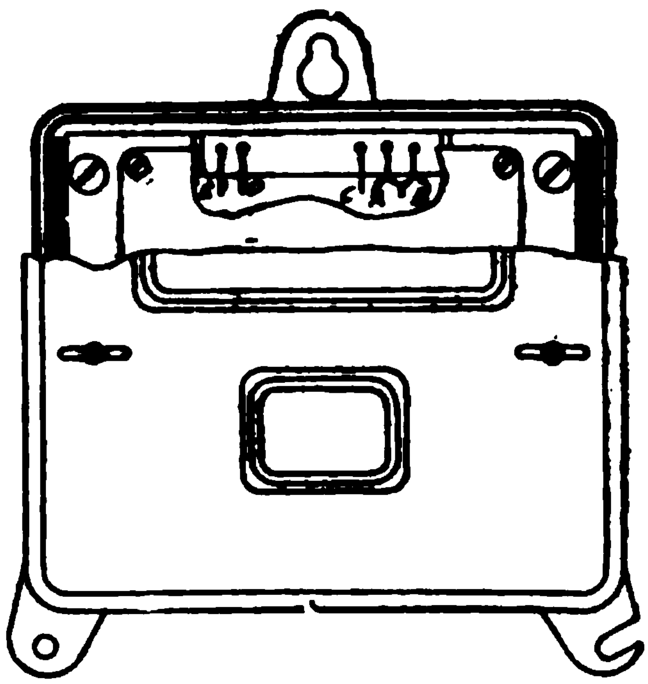


Fig. 478.—Connections of Thomson, Type I, Single-phase, Induction, House Pattern Watt-hour Meters, Showing Method of Making Connections for Double Lag Adjustment.

This sketch shows the connections made for the higher of the two frequencies. If it is desired to run the meter on a lower frequency, disconnect the wire A from B and solder A to C. Make a soldered connection between D and E. No other change is required except that it may be necessary to readjust on light load.

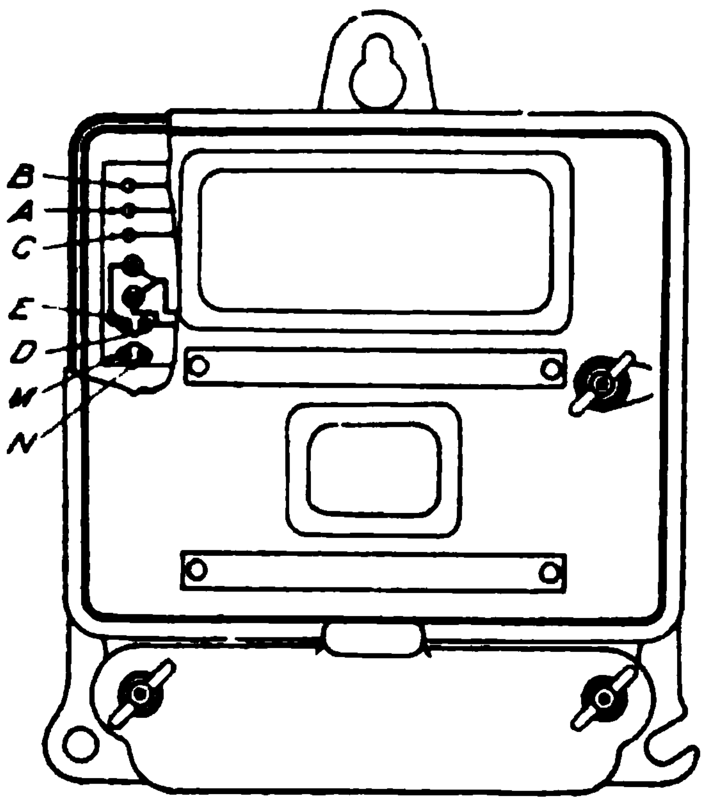


Fig. 479.—Connections of Potential Circuit of Thomson, Type I-8, Single-phase, Induction, House Pattern Watt-hour Meters, Showing Method of Making Connections for Double Lag Adjustment.

For lower frequencies A must be soldered to C and D to E. For higher frequencies A must be soldered to B and D and E left open circuited.

Testing Loop: If it is desired to test meter on separate potential circuit, M and N should be opened and line connection made to N.

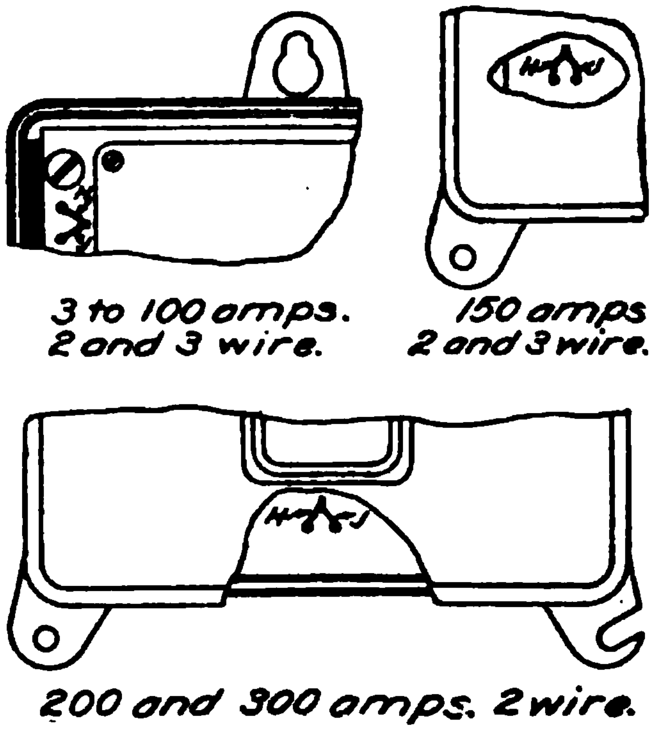


FIG. 480.—Connections of Thomson, Type I, Single-phase, Induction, House Pattern Watt-hour Meters, Showing Method of Making Connections for Testing upon Separate Potential.

If it is desired to test with separate potential connections, unsolder H and J. Connect J to one side of the source. In two-wire meters and in three-wire 150 amp. meters, connect the opposite side of source to upper right-hand terminal. In three-wire meters 3 to 100 amps. connect opposite side of source to central right-hand terminal.

External Connection Diagrams

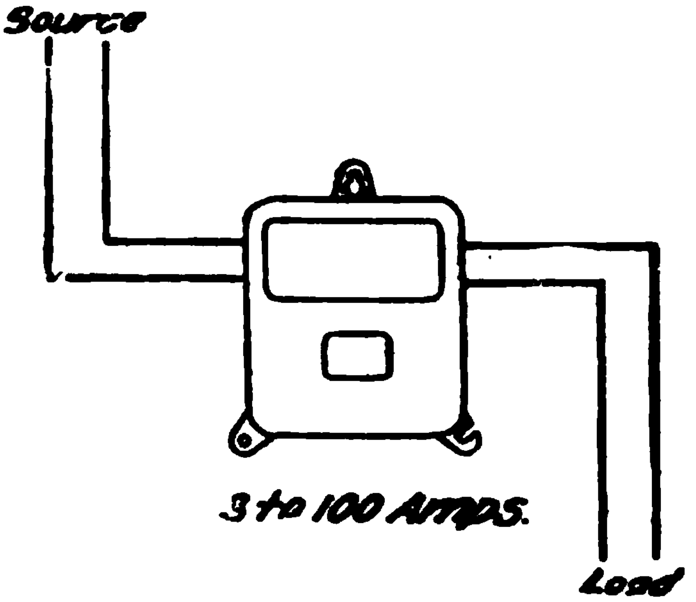


Fig. 481.—External Connections of Thomson, Type I, Single-phase, Induction Watt-hour Meters, 3-100 Amps., 0–650 Volts, 25–140 Cycles, 2-wire, without Instrument Transformers.

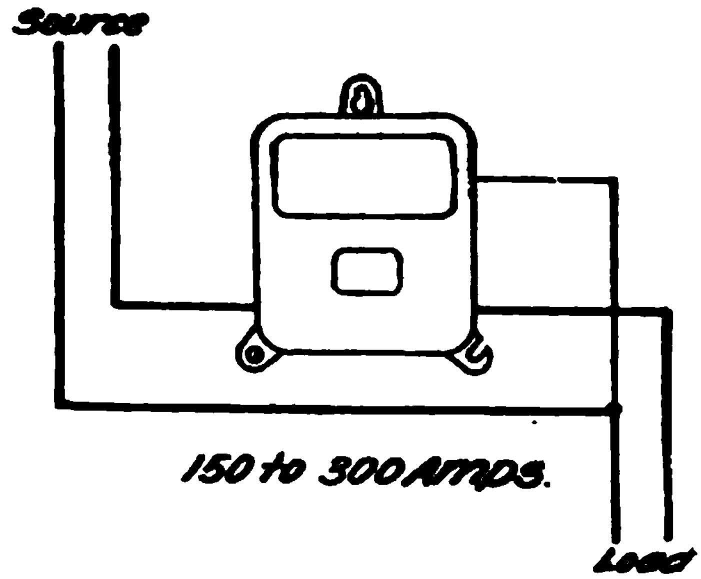


Fig. 482.—External Connections of Thomson, Type I, Single-phase, Induction Watt-hour Meters, 150–300 Amps., 0–650 Volts, 25–140 Cycles, 2-wire, without Instrument Transformers.

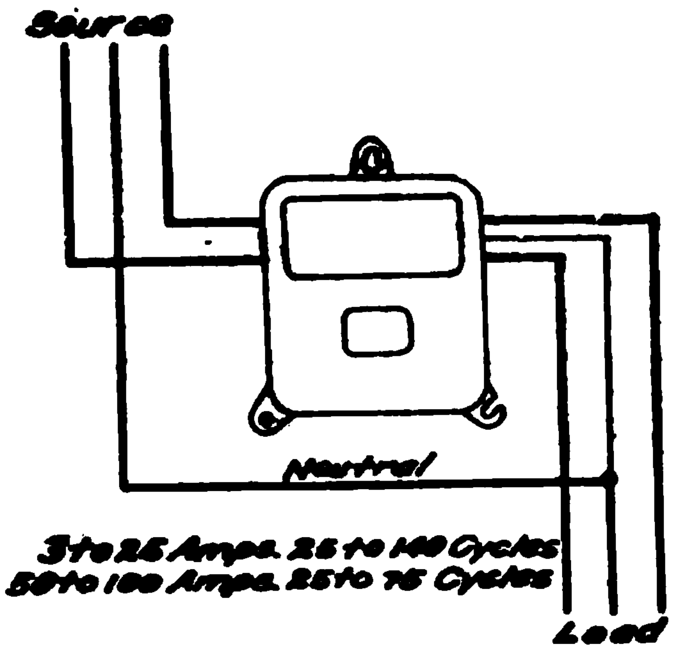


Fig. 483.—External Connections of Thomson, Type I, Single-phase, Induction Watt-hour Meters, 3 to 25 Amps., 200–650 Volts, 25–140 Cycles, 3-wire, without Instrument Transformers, Front View. 50 to 100 Amps., 200-650 Volts, 25–75 Cycles, 3-wire, without Instrument Transformers.

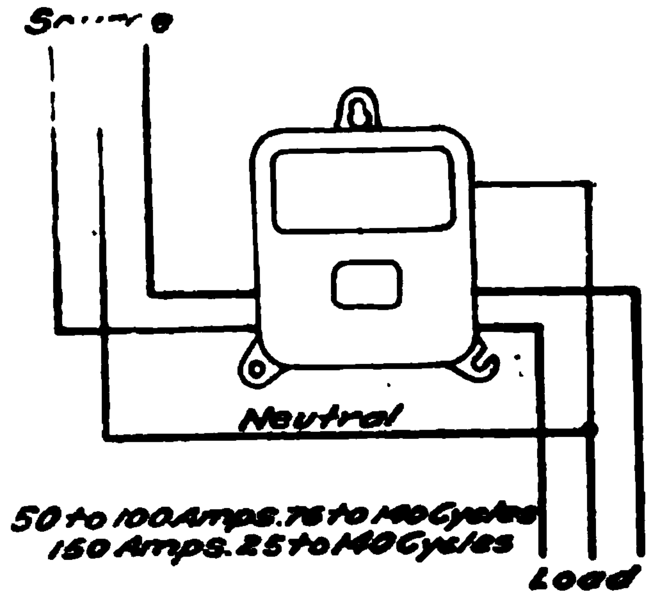


Fig. 484.—External Connections of Thomson, Type I, Single-phase, Induction Watt-hour Meters, 50 to 100 Amps., 200-650 Volts, 76–140 Cycles, 3-wire, without Instrument Transformers.

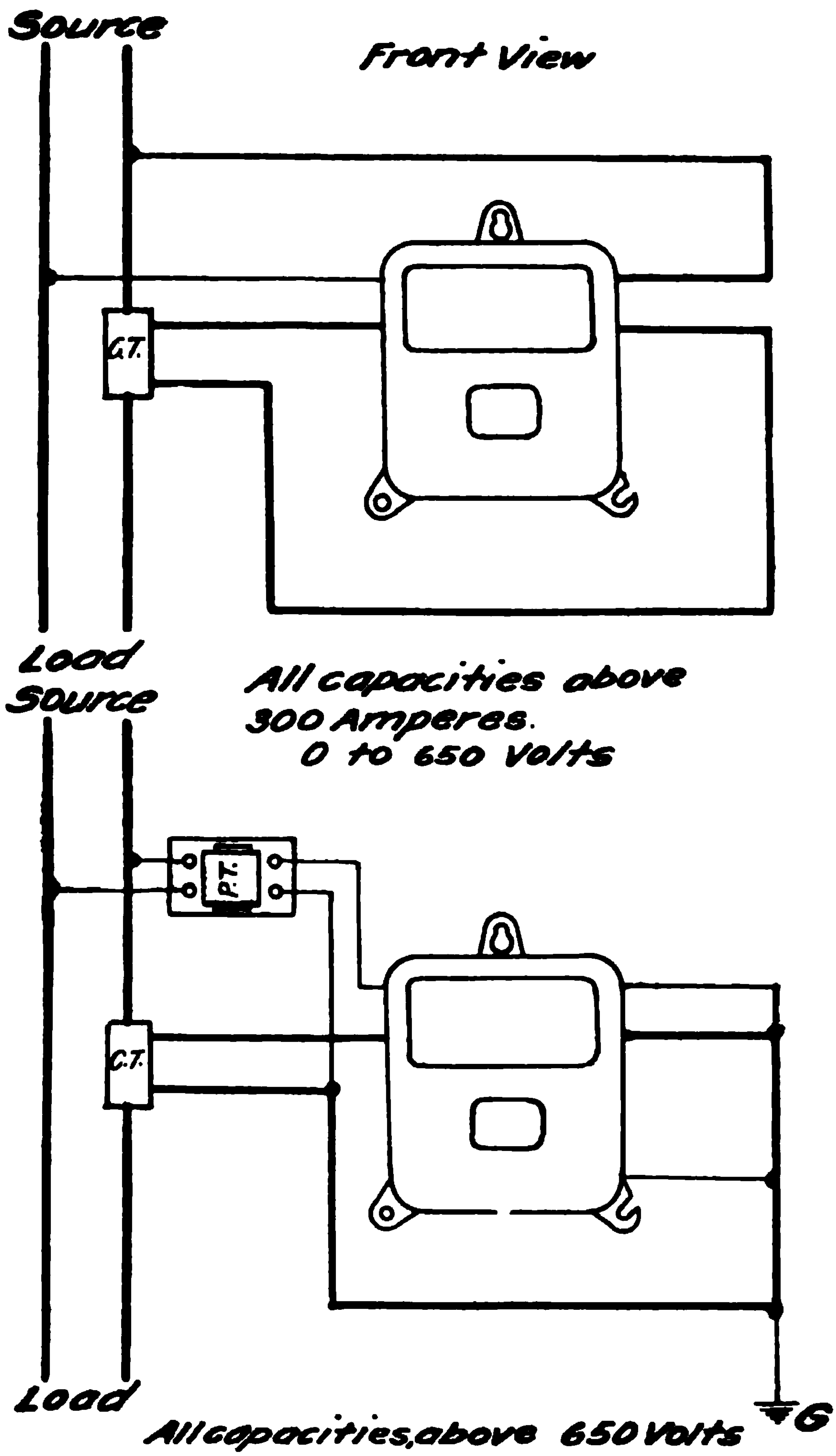


Fig. 485.—External Connections of Thomson, Type I, Single-phase, Induction Watt-hour Meters, with Instrument Transformers.

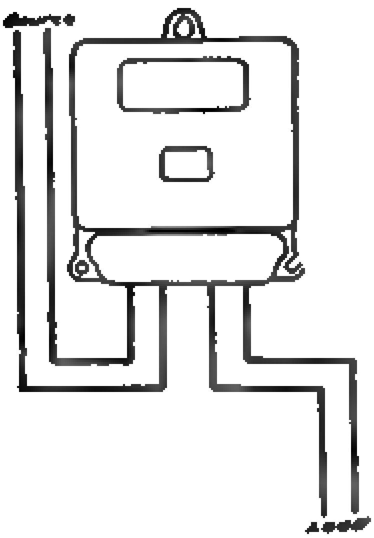


FIG. 486.—External Connections of Thomson, Type I-8, Single-phase Watt-hour Meters, 3-75 Amps., 0-650 Volts, 2 wire, 25-140 Cycles, without Instrument Transformers.

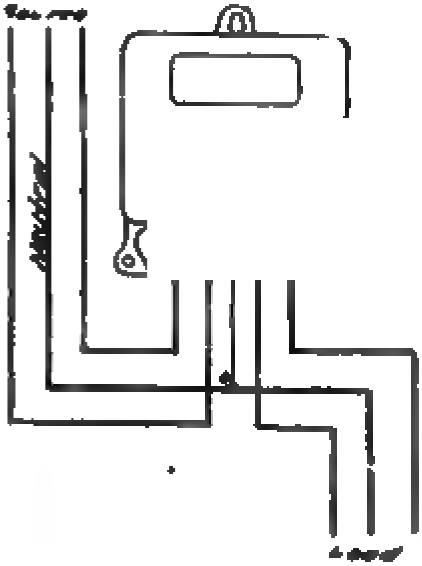


FIG. 487.—External Connections of Thomson, Type I-8, Single-phase Watt-hour Meters, 3-75 Amps., 200-650 Volts, 3-wire, 25-140 Cycles, without Instrument Transformers.

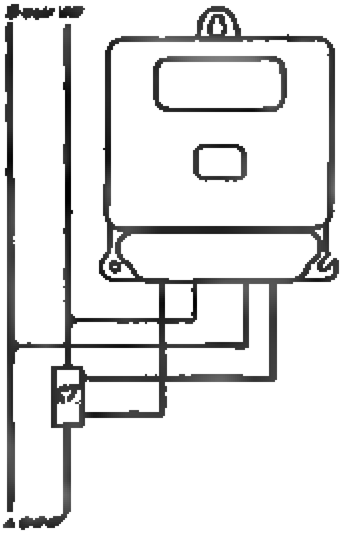


FIG. 488.—External Connections of Thomson, Type I-8, Single-phase Watt-hour Meters, above 75 Amps., 0-650 Volts, 2-wire, 25-140 Cycles, with Current Transformers.

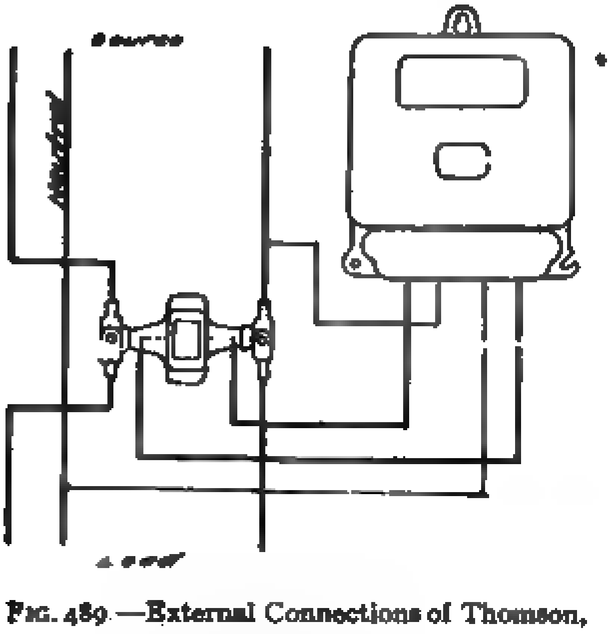


FIG. 489.—External Connections of Thomson, Type I-8, Single phase, Induction Watt-hour Meters, above 75 Amps., 0-650 Volts, 3-wire, 25-140 Cycles, with Form DM-16 Current Transformers.

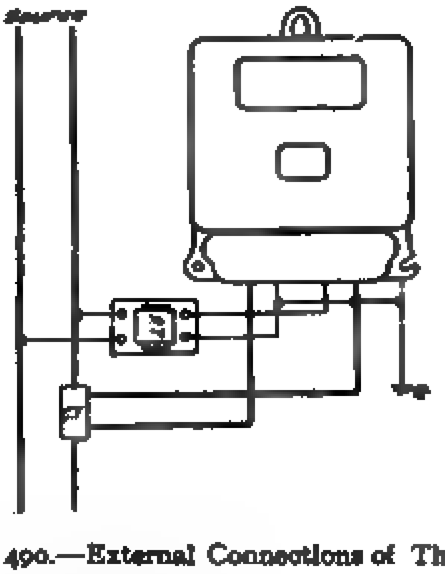


FIG. 490.—External Connections of Thomson, Type I-8, Single-phase, Induction Watt-hour Meters, above 650 Volts, 2-wire, 25-140 Cycles, with Current and Voltage Transformers.

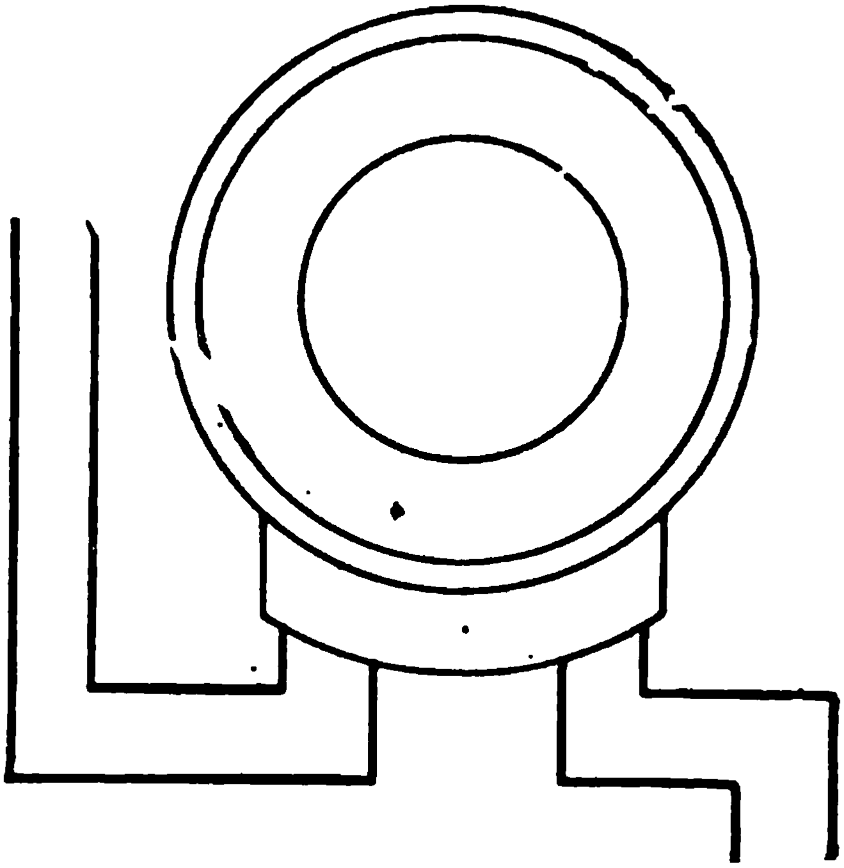


FIG. 491.—External Connections of Thomson, Type I–10, Single-phase, Induction Watt-hour Meters, 5–10 Amps., 100–240 Volts, 2-wire.

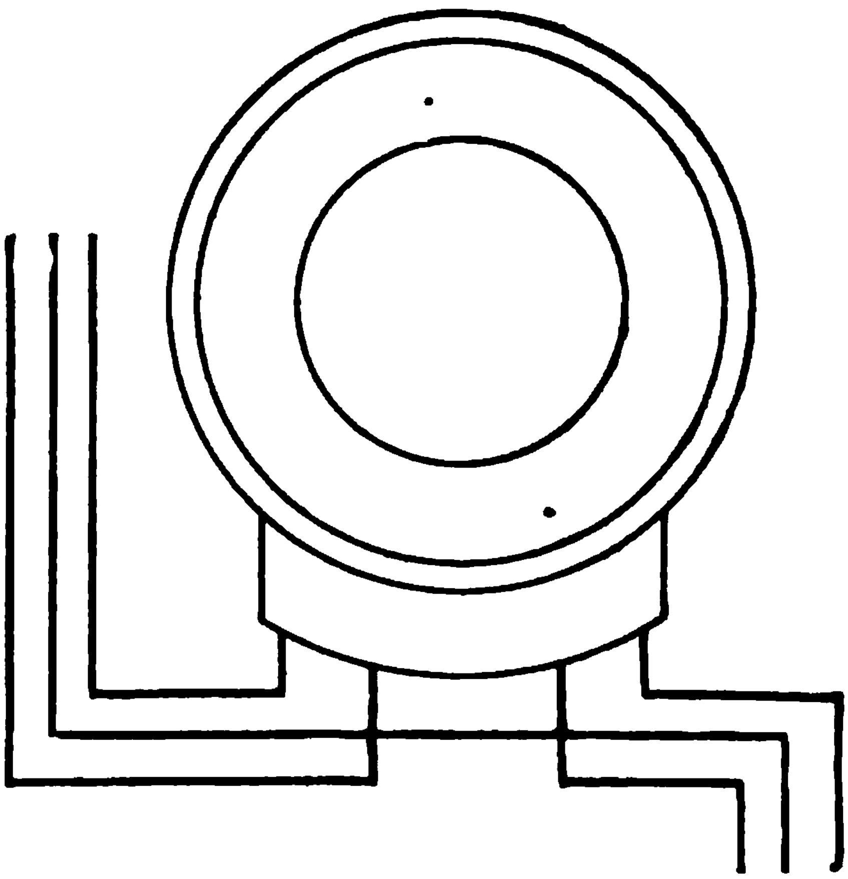


FIG. 492.—External Connections of Thomson, Type I–10, Single-phase, Induction Watt-hour Meters, 5–10 Amps., 200–240 Volts, 3-wire.

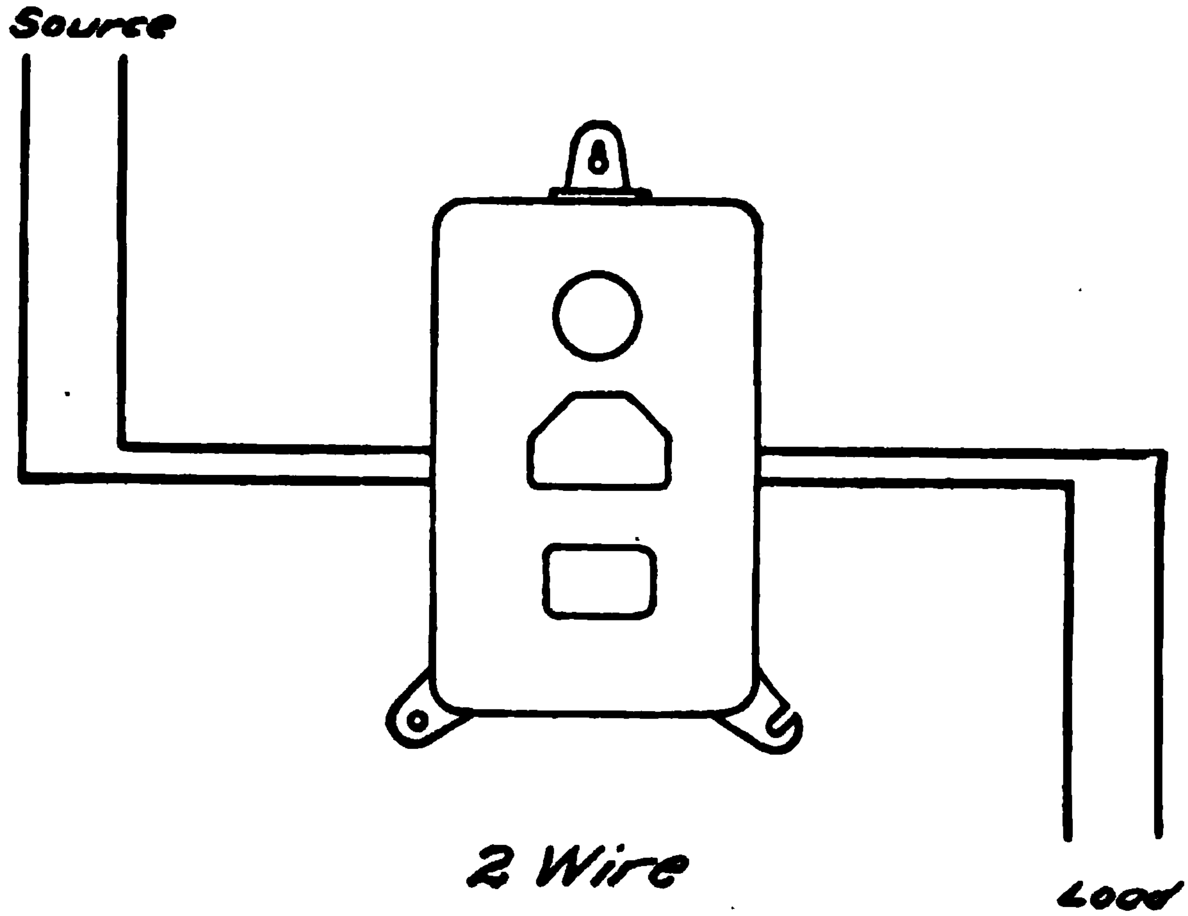


FIG. 493.—**External Connections of Thomson, Type IP-4, Single-phase, Prepayment, Induction Watt-hour Meters, 3-25 Amps.; 0-250 Volts, 2-wire, 25-140 Cycles, without Instrument Transformers.**

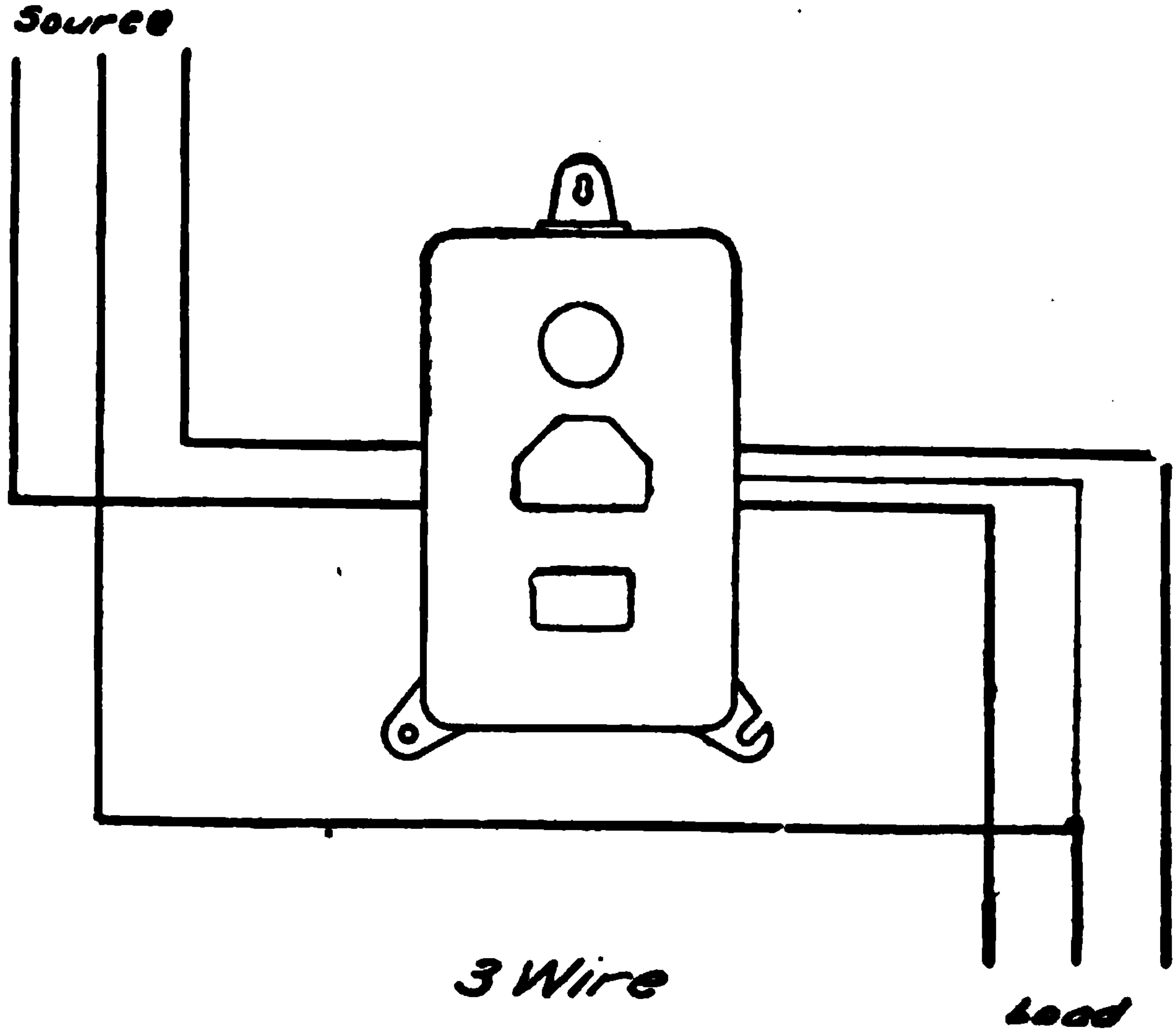


FIG. 494.—**External Connections of Thomson, Type IP-4, Single-phase, Prepayment, Induction Watt-hour Meters, 3-25 Amps., 0-250 Volts, 3-wire, 25-140 Cycles, without Instrument Transformers.**

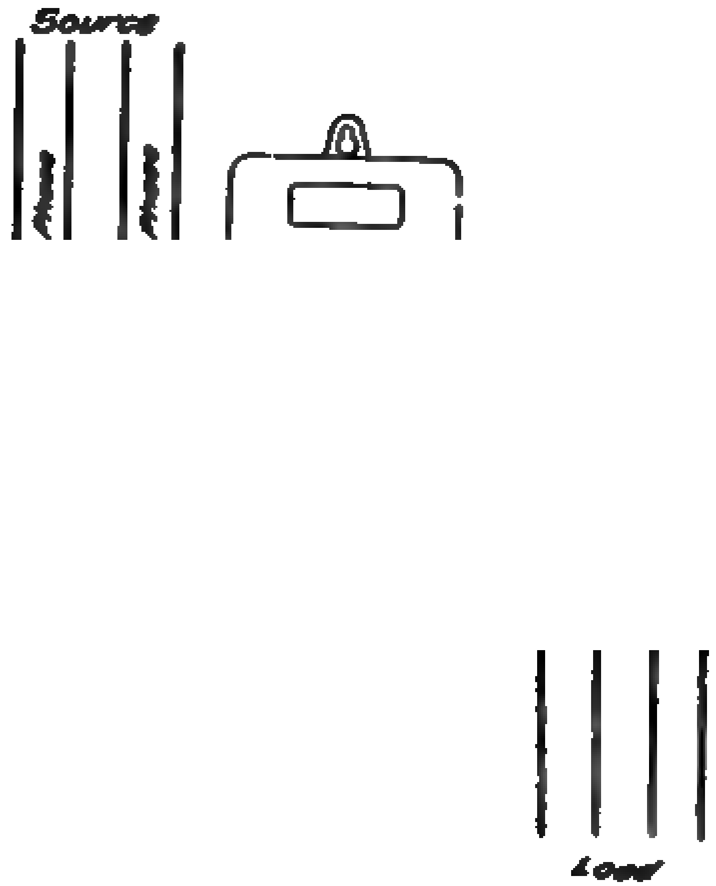


FIG 495.—External Connections of Thomson, Type D-3, Polyphase, Induction Watt-hour Meters, 3-150 Amps., 0-650 Volts, 25 Cycles and above; 4-wire, 2-phase Circuits without Instrument Transformers. Front View.

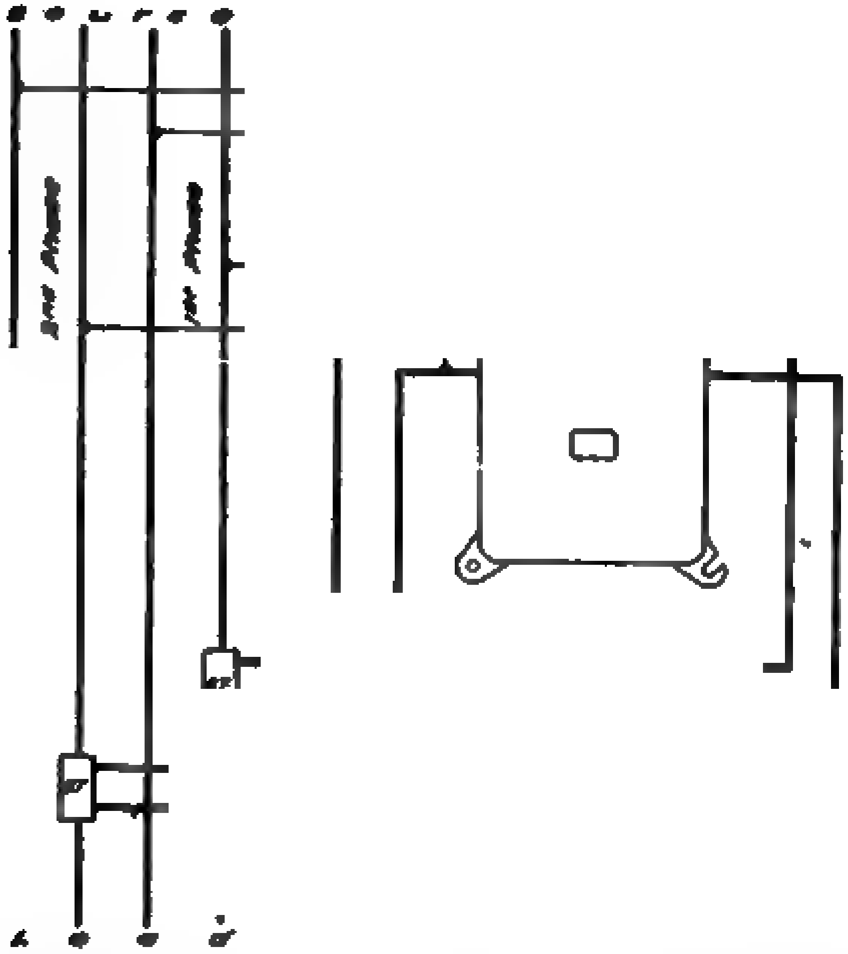


FIG. 496.—External Connections of Thomson, Type D-3, Polyphase, Induction Watt-hour Meters, above 150 Amps., not exceeding 1150 Volts, 25 Cycles and above; 4-wire, 3-phase Circuits with Current Transformers. Front View.

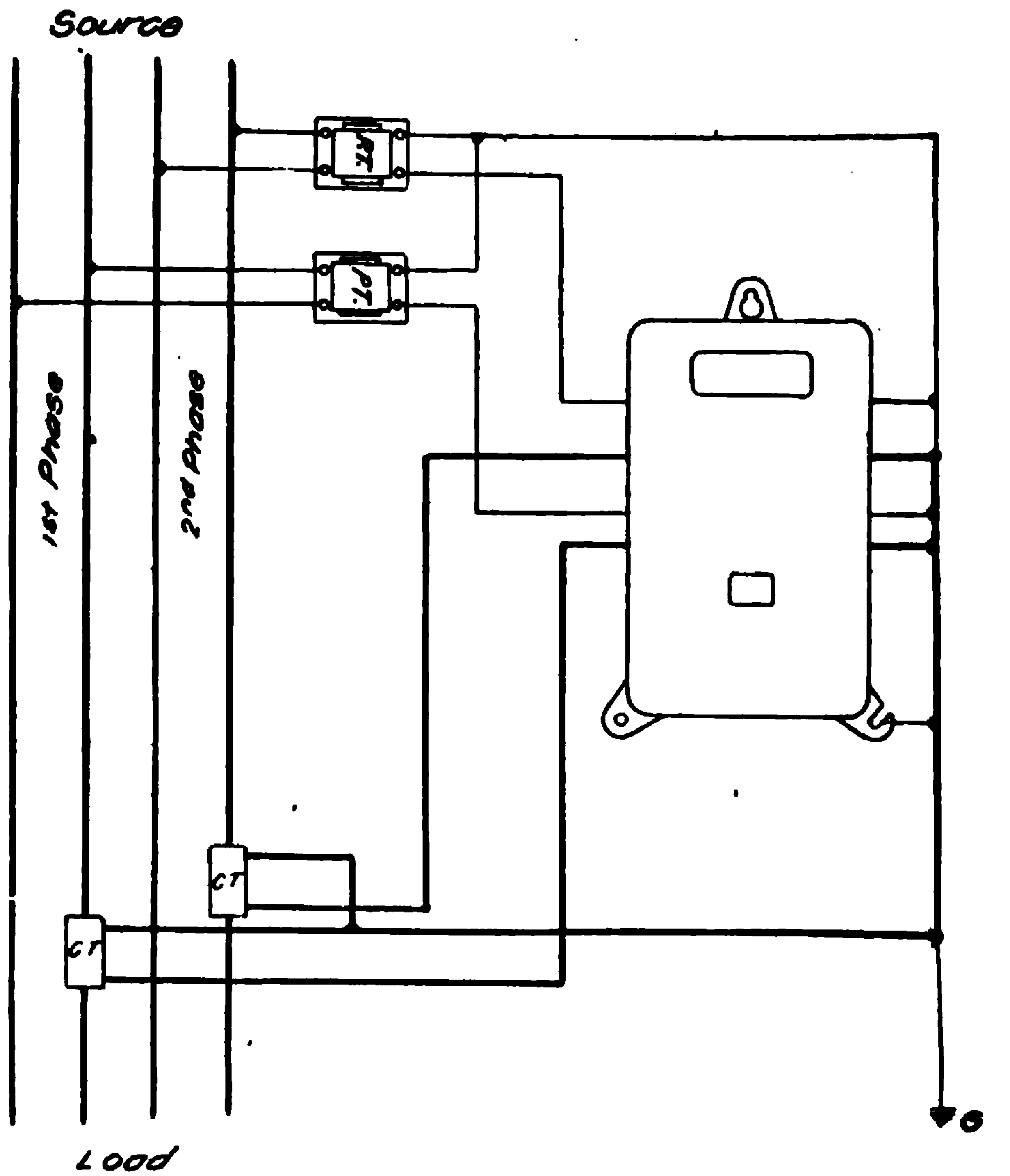


FIG. 497.—External Connections of Thomson, Type D-3, Polyphase, Induction Watt-hour Meters, above 1150 Volts, 25 Cycles and above; 4-wire, 2-phase Circuits with Current and Voltage Transformers. Front View.

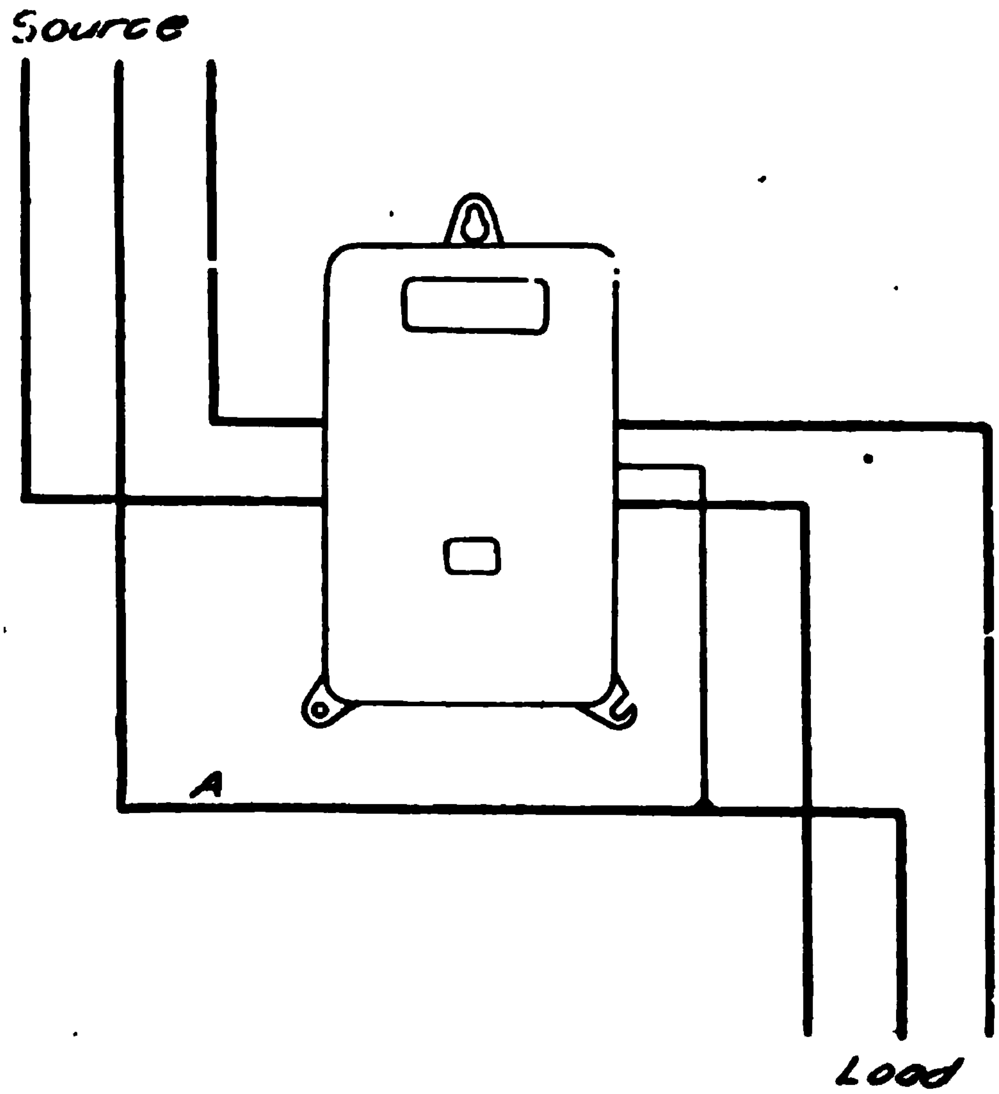


FIG. 498.—External Connections of Thomson, Type D–3, Polyphase, Induction Watt-hour Meters, 3–150 Amperes, 0–650 Volts, 25 Cycles and above; 3-wire, 2- and 3-phase and Monocyclic Circuits without Instrument Transformers. Front view.

On 3-wire, 2-phase circuits, wire "A" should be the common return; on monocyclic circuits, wire "A" must be the teaser wire.

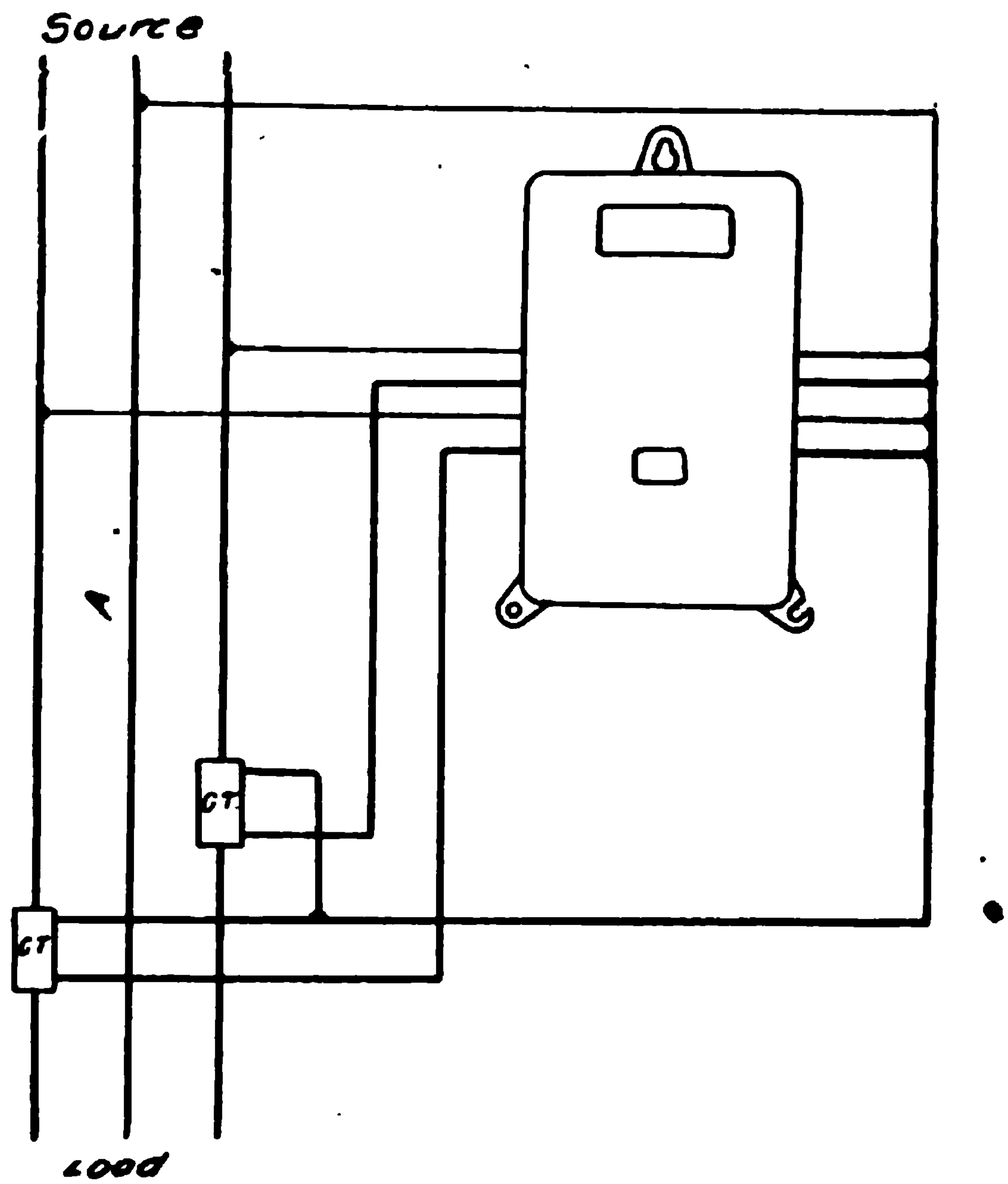


FIG. 499.—External Connections of Thomson, Type D–3, Polyphase, Induction Watt-hour Meters, above 150 Amperes, not exceeding 1150 Volts, 25 Cycles and above; 3-wire, 2- and 3-phase and Monocyclic Circuits, with Current Transformers. Front View.

On 3-wire, 2-phase circuits, wire "A" should be the common return; on monocyclic circuits, wire "A" must be the teaser wire.

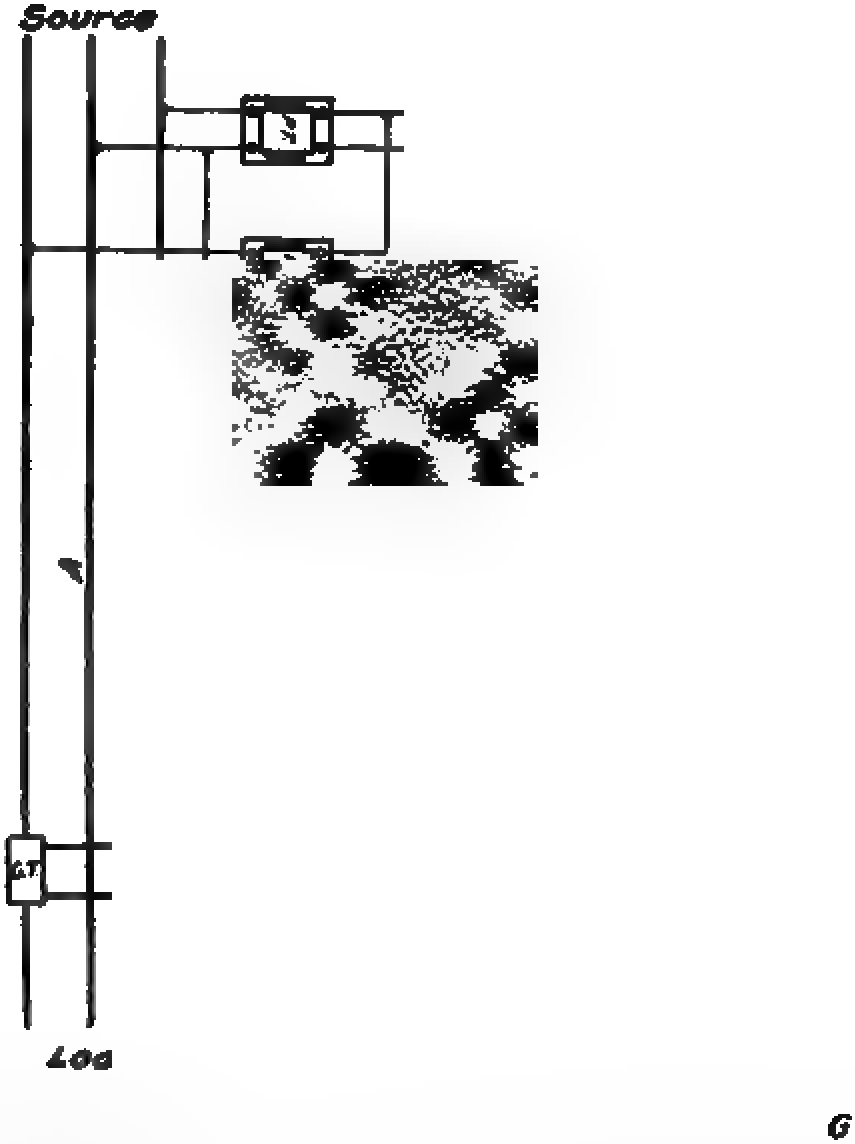


FIG. 500.—External Connections of Thomson, Type D-3, Polyphase, Induction Watt-hour Meters, above 1150 Volts, 25 Cycles and above; 3-wire, 2- and 3-phase and Monocyclic Circuits; with Current and Voltage Transformers.

On 3-wire, 2-phase circuits, wire "A" should be the common return; on monocyclic circuits, wire "A" must be the teaser wire.

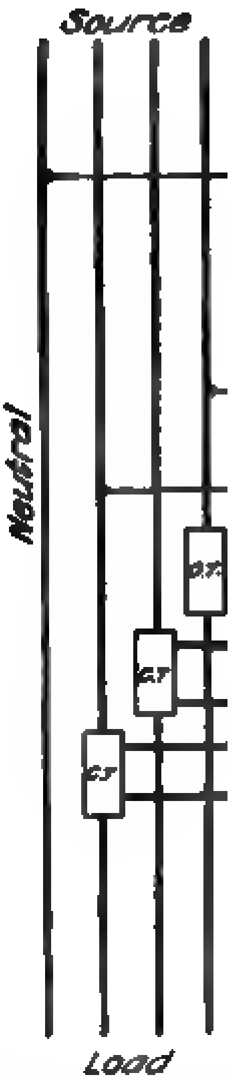


Fig. 501.—External Connections of Thomson, Type D-4, Polyphase, Induction Watt-hour Meters, above 75 Amperes, not exceeding 1150 Volts, 25 Cycles and above; 4-wire, 3-phase Circuits with Current Transformers. Front View.

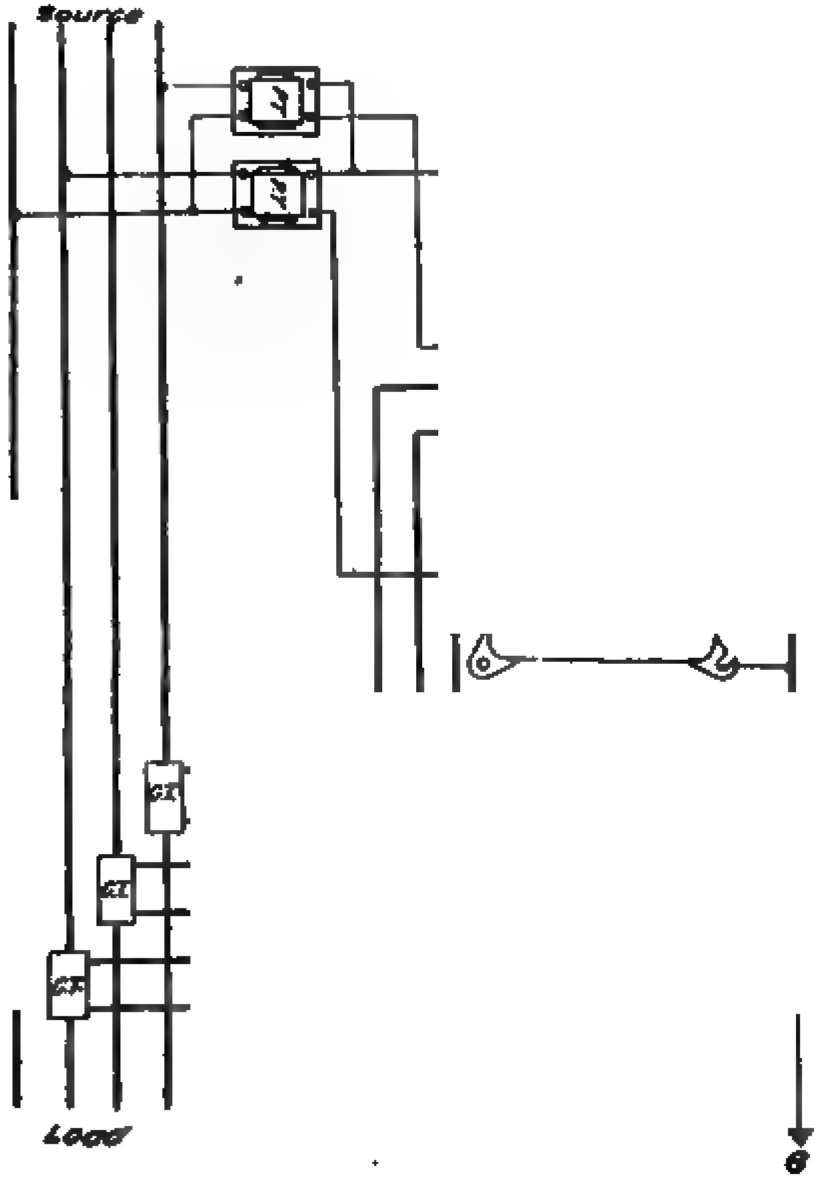


FIG. 502.—External Connections of Thomson, Type D-3, Polyphase, Induction Watt-hour Meters, above 1150 Volts, 25 Cycles and above; 4-wire, 3-phase Circuits with Current and Potential Transformers. Front View.

Dimension Diagrams

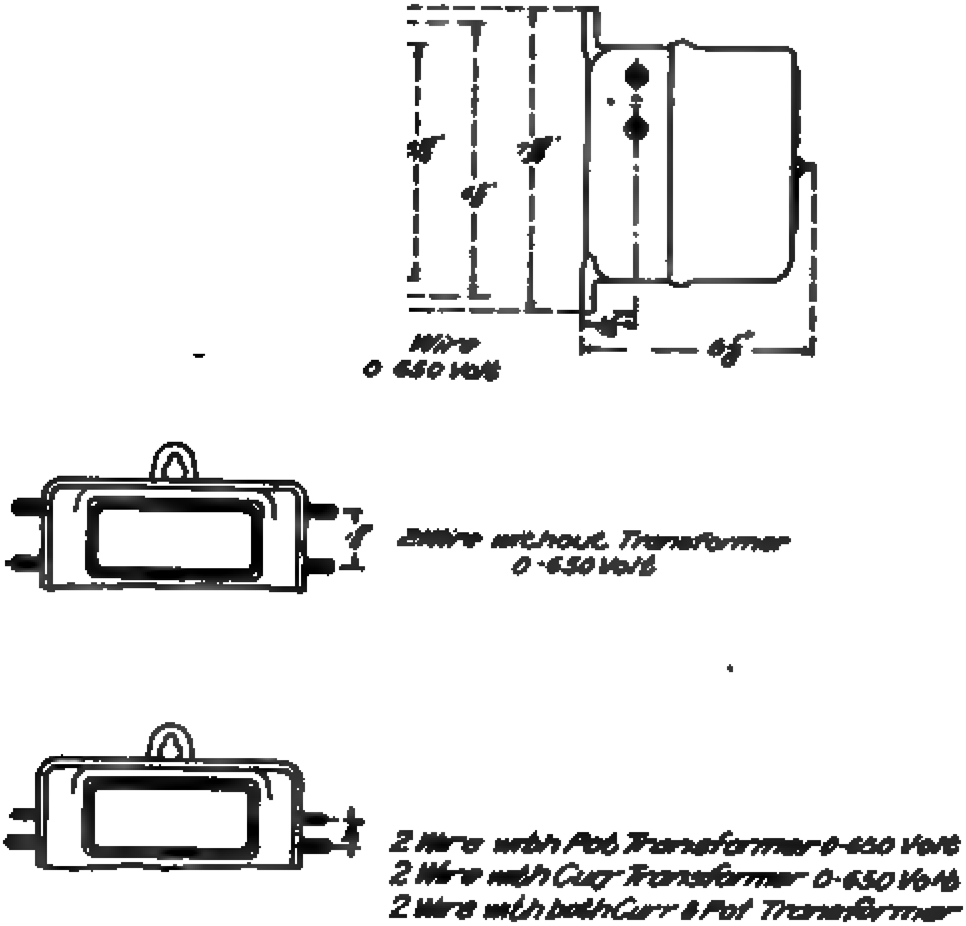


Fig. 503.—Dimensions of Thomson, Types I and IP, Single-phase, Induction Watt-hour Meters, 3–25 Amperes, 0–650 Volts, 25–140 Cycles, 2- and 3-wire with and without Instrument Transformers.

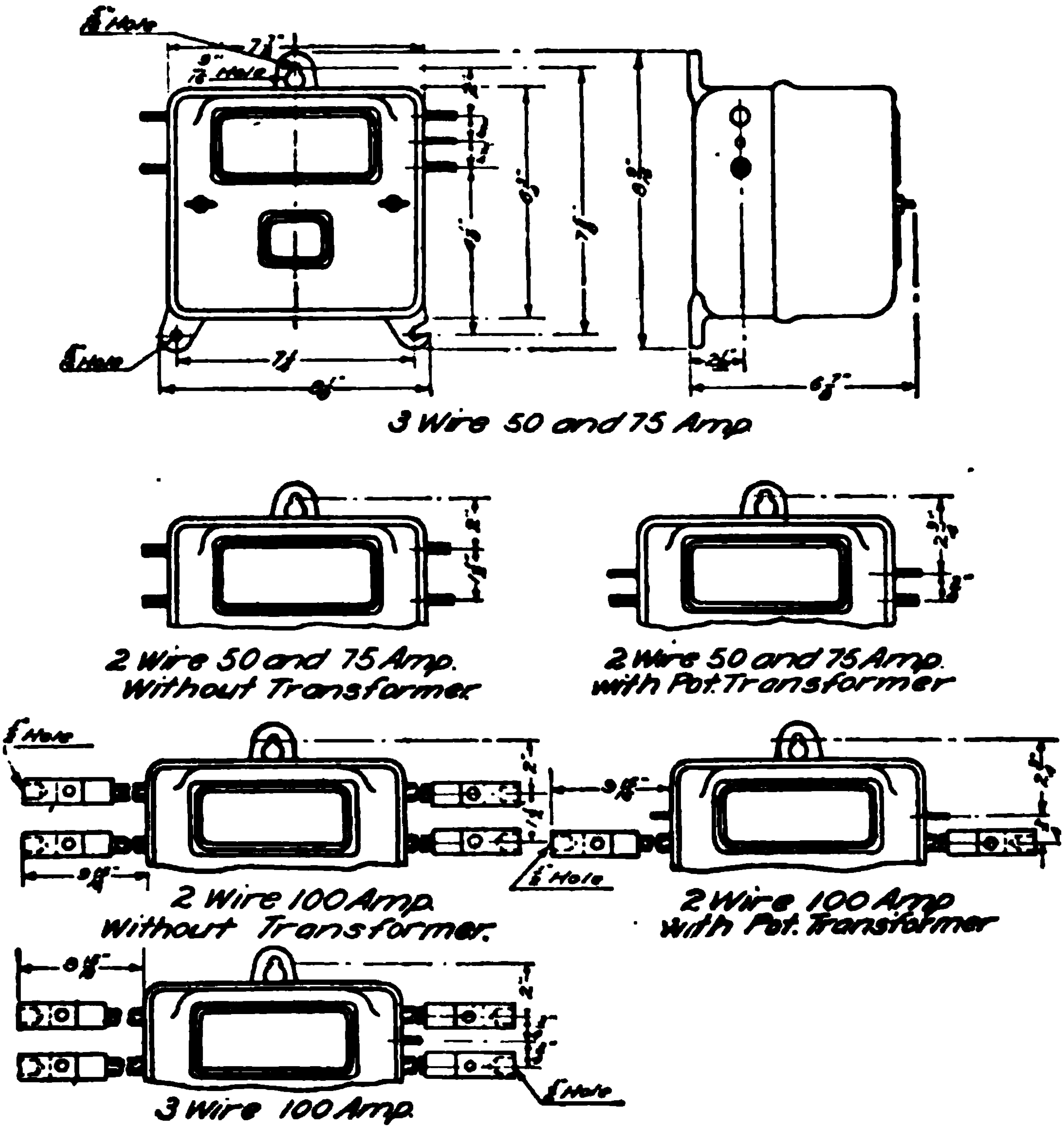


FIG. 504.—Dimensions of Thomson, Type I, Single-phase, Induction Watt-hour Meters, 50–100 Amperes, 0–650 Volts, 25–140 Cycles, 2-wire with and without Instrument Transformers.

50–100 Amperes, 200–650 Volts, 25–75 Cycles (Single Lag Adjustment) 3-wire without Instrument Transformers.

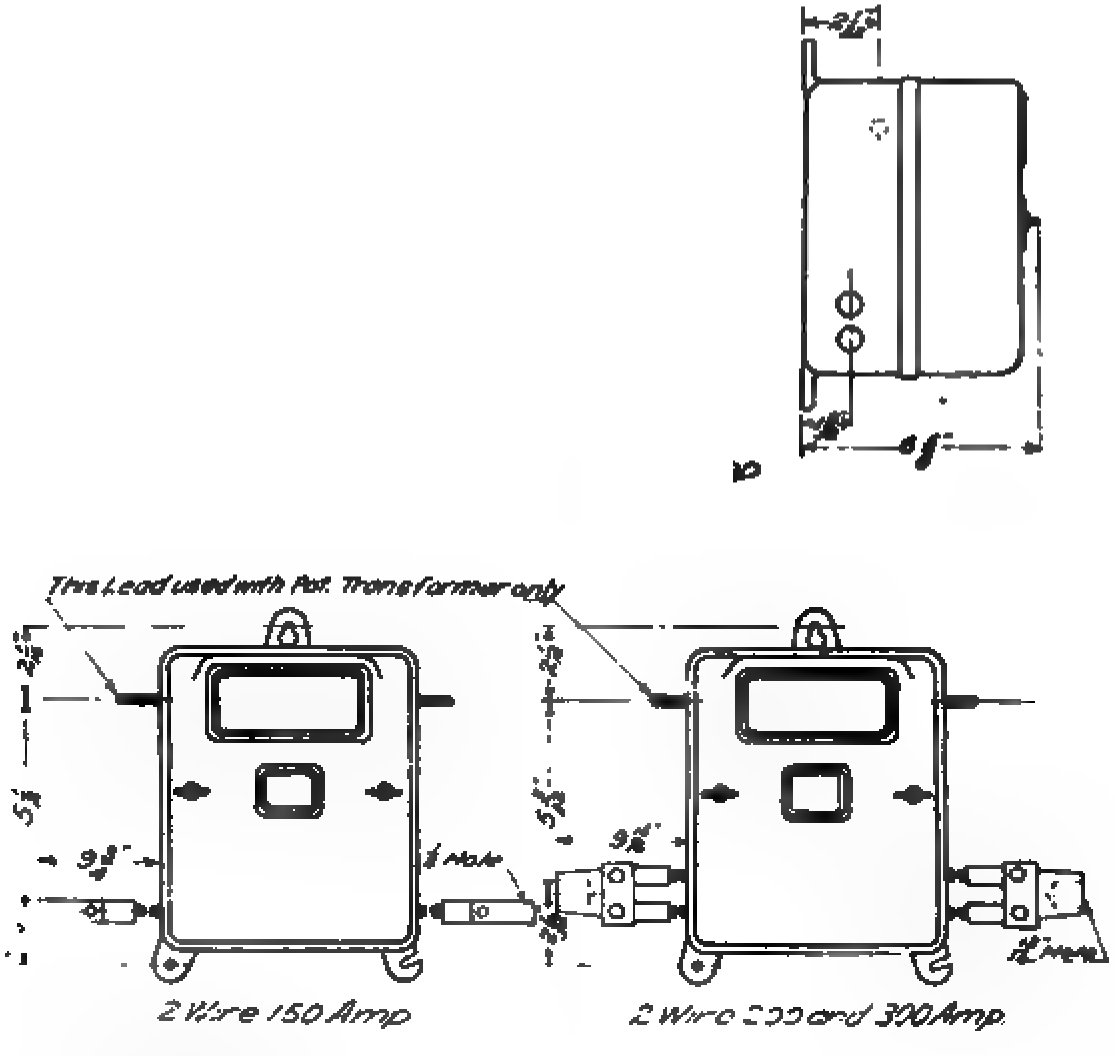


FIG. 505.—Dimensions of Thomson, Type I, Single-phase, Induction Watt-hour Meters, 50–100 Amperes, 200–650 Volts, 76–140 Cycles (Double Lag Adjustment) 3-wire without Instrument Transformers.

150 Amperes, 0–650 Volts, 25–140 Cycles, 2– and 3-wire without Instrument Transformers.

200 and 300 Amperes, 0–650 Volts, 25–140 Cycles, 2-wire without Instrument Transformers

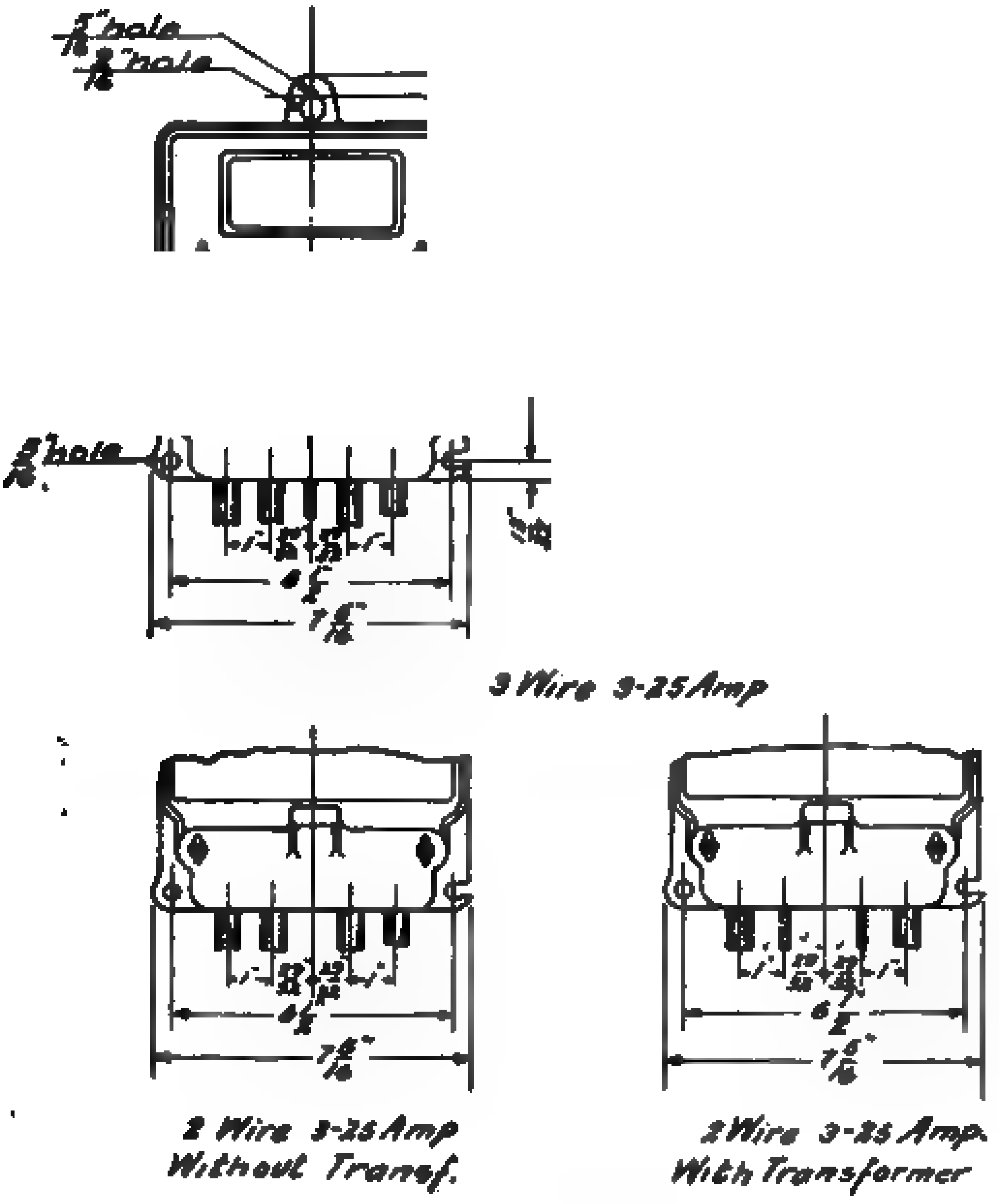


FIG. 506.—Dimensions of Thomson, Type I-8, Single-phase, Induction Watt-hour Meters, 3-25 Amperes, 0-650 Volts, 25-140 Cycles, 2- and 3-wire with and without Instrument Transformers.

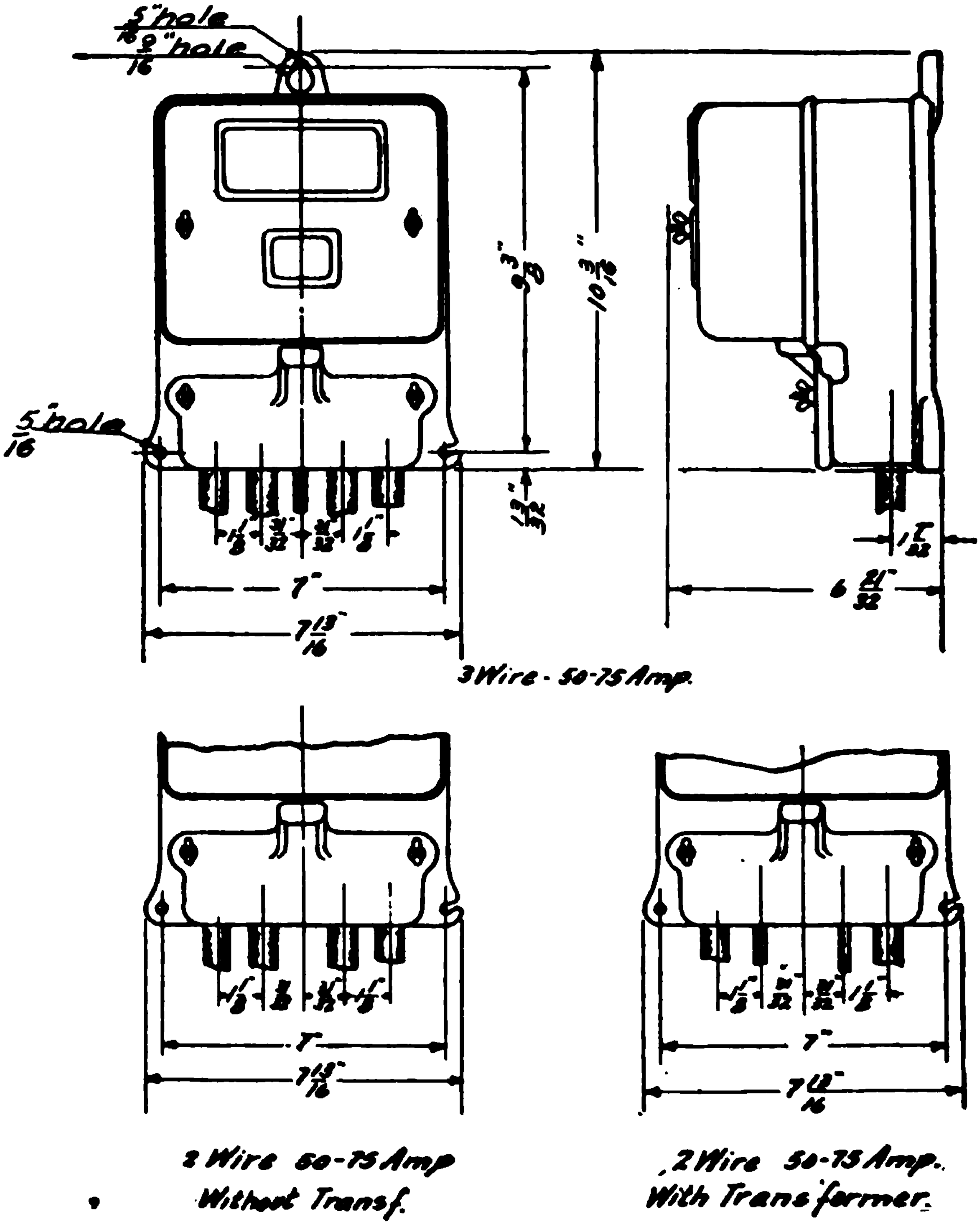


FIG. 507.—Dimensions of Thomson, Type I-8, Single-phase, Induction Watt-hour Meters, 50-75 Amperes, 0–650 Volts, 25–140 Cycles, 2- and 3-wire with and without Instrument Transformers.

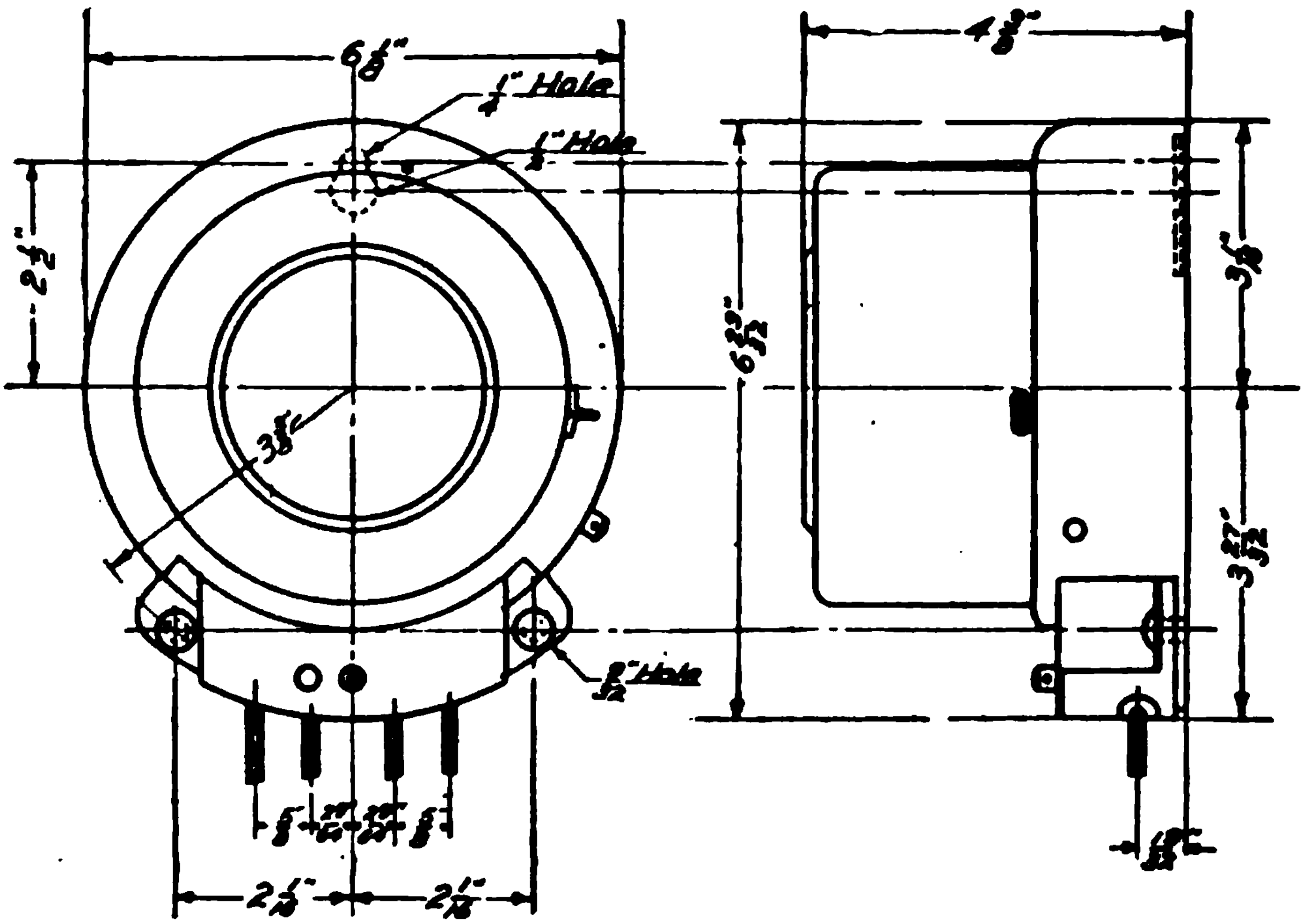


FIG. 508.—Dimensions of Thomson, Type I-10, Single-phase, Induction Watt-hour Meters, 5-10 Amperes, 100-240 Volts, 2-wire, 200-240 Volts, 3-wire, 60 Cycles.

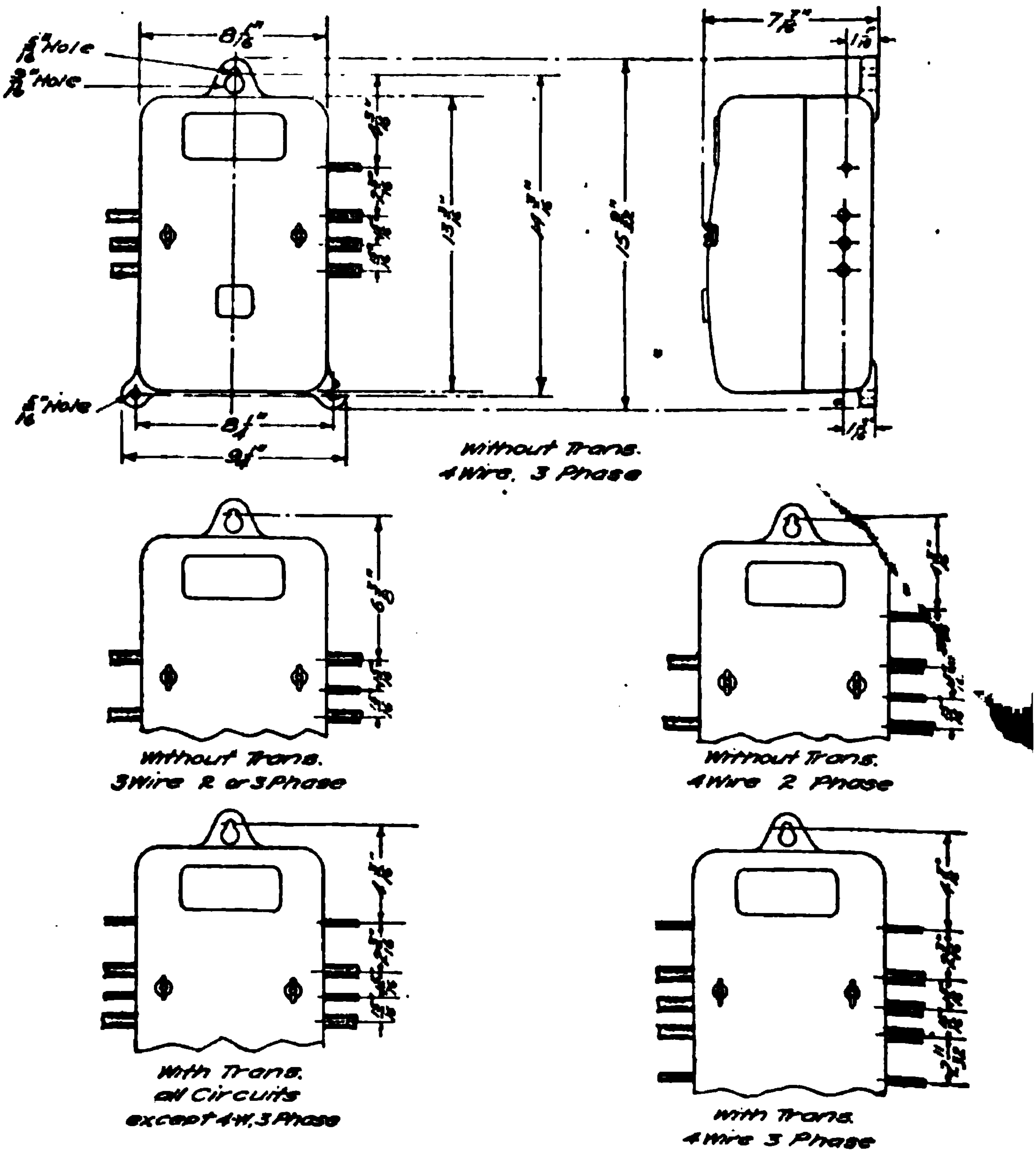


FIG. 509.—Dimensions of Thomson, Type D-3, Polyphase, Induction Watt-hour Meters, 3-: Amperes, 0-650 Volts, 25 Cycles and above; all Circuits with and without Instrume Transformers.

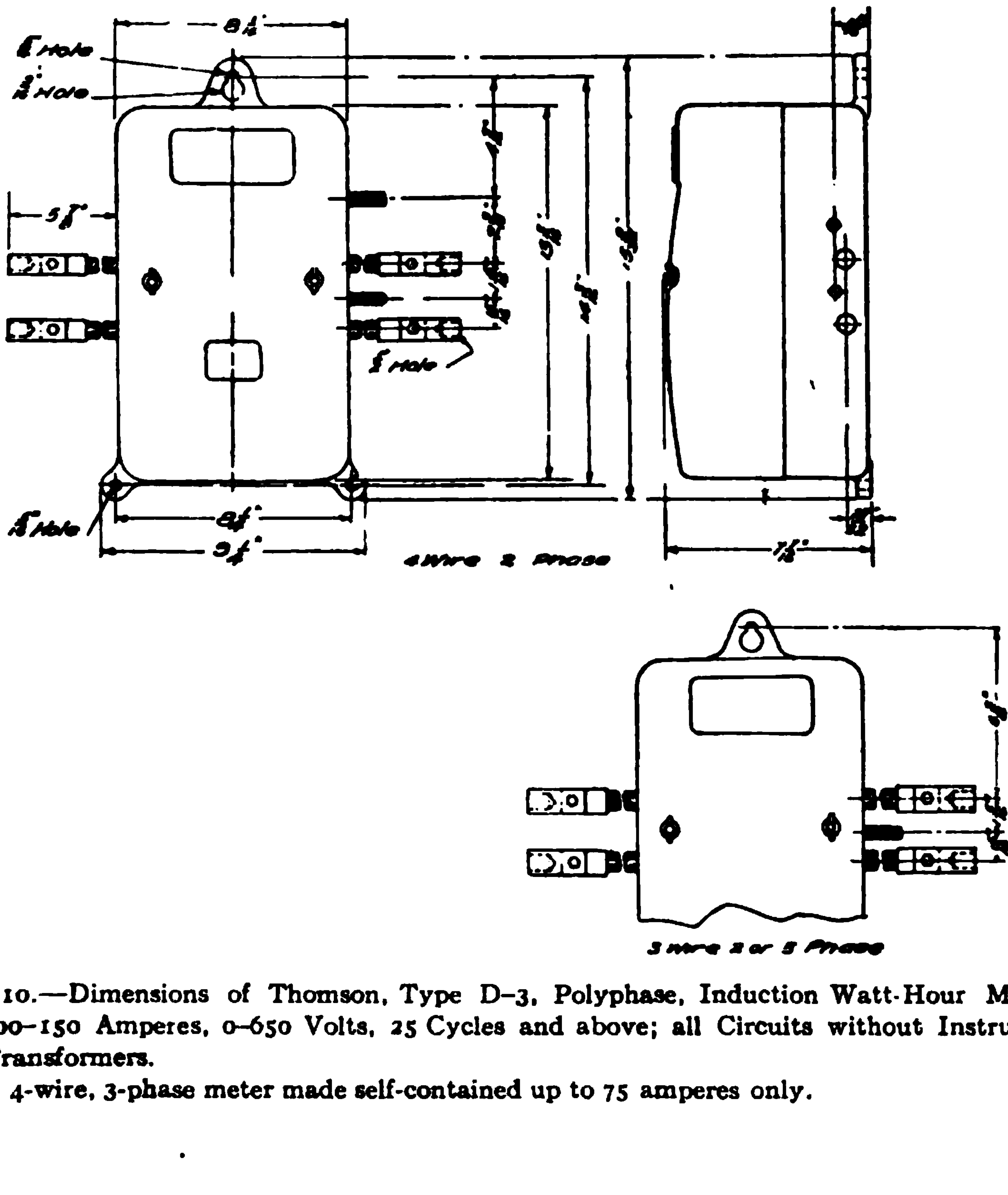


FIG. 510.—Dimensions of Thomson, Type D-3, Polyphase, Induction Watt-Hour Meters. 100–150 Amperes, 0–650 Volts, 25 Cycles and above; all Circuits without Instrument Transformers.

4-wire, 3-phase meter made self-contained up to 75 amperes only.

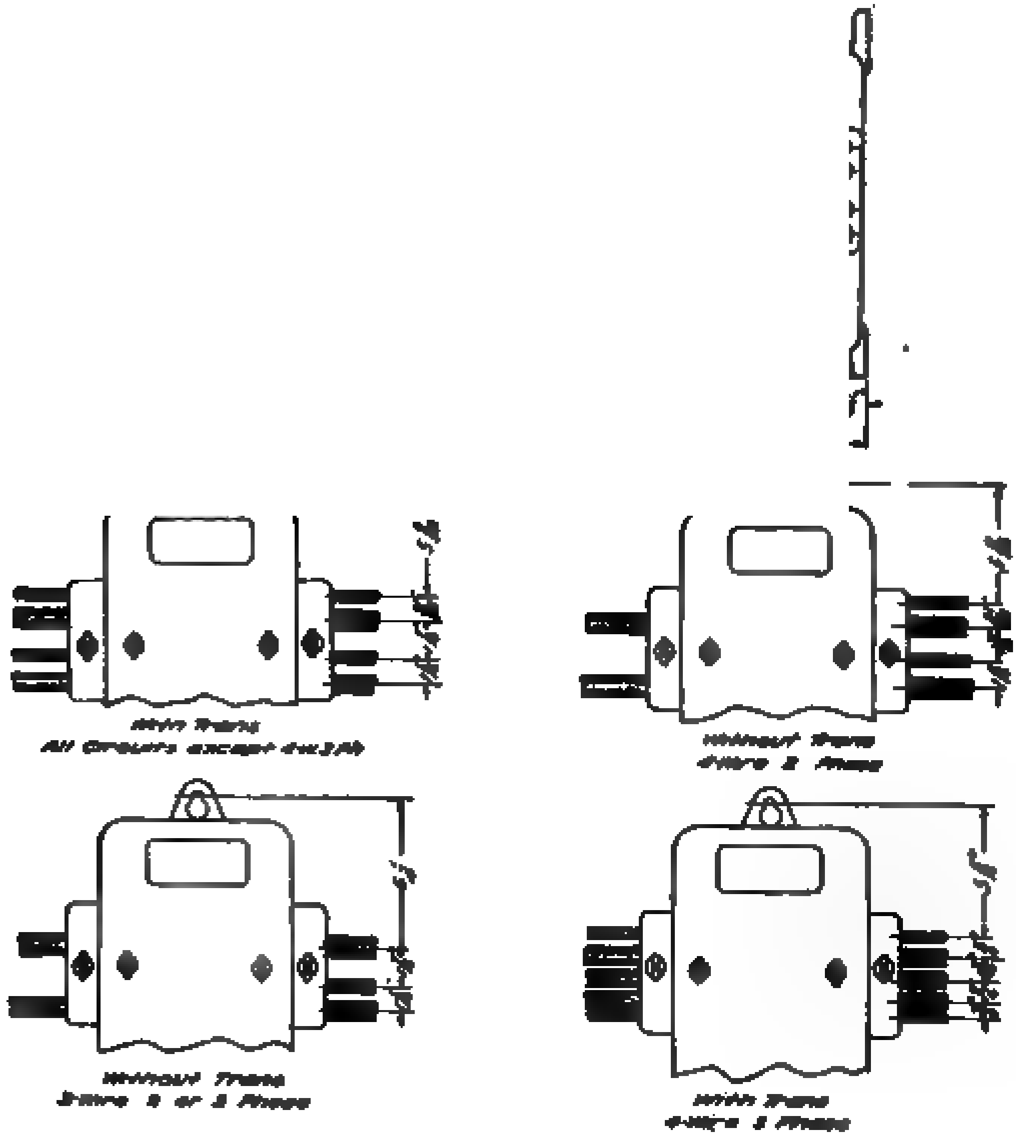


Fig. 511.—Dimensions of Thomson, Type D-4, Polyphase, Induction Watt-hour Meters, 3-75 Amperes, 0-650 Volts, 25 Cycles and above, all Circuits with and without Instrument Transformers.

WESTINGHOUSE ALTERNATING CURRENT WATT-HOUR METERS

The Westinghouse induction watt-hour meter for alternating current circuits is in principle an induction motor generator provided with a suitable registering mechanism.

Every commercial watt-hour meter of this type is made up of a number of elements, described below. Each of these elements and parts has certain functions, and is therefore necessary to the successful operation of the meter. On the other hand, each element, unless correctly designed, may introduce a source of inaccuracy. These elements are: the field producing element; the moving element; the retarding element; the registering element; the mounting frame and bearings; the friction compensator; the power-factor and frequency adjustment; the case and cover.

The **field producing element** consists of the electromagnetic circuit and the measuring coils. One of these coils, connected in series with the circuit to be metered, is wound of few turns and is therefore of low inductance. The current through it is in phase with the current in the metered circuit. The other coil, connected across the circuit, is highly inductive, and therefore the current in it is nearly 90 degrees out of phase with and proportional to the voltage of the metered circuit across its terminals. Therefore, when the current in the circuit is in phase with the voltage (100 per cent power-factor) the currents in the meter coils are displaced almost 90 degrees with respect to each other. This angle is made exactly 90 degrees by means of the "power-factor adjustment." The coils are so mounted on the core that the currents in them produce a rotating or shifting field in the air gap, in somewhat the same manner that the currents in the primary windings of an induction motor produce a rotating field. The strength of this shifting field with 90 degrees phase difference between the current in the two coils is therefore proportional to the product of the current and voltage in the metered circuit. At any other power-factor the field is proportional to this product multiplied by the sine of the angle of phase difference between the two watt-hour meter currents. If the current in the potential coil is exactly in quadrature with the voltage of the metered circuit, at any power-factor, the sine of the angle of phase difference between the currents in the watt-hour meter circuits will be equal to the cosine of the angular displacement between the current and the voltage in the metered circuit. Under these conditions, therefore,

the strength of the shifting field is proportional also to the power-factor of the circuit. In other words, the strength of the rotating fields is proportional to the product of the volts, amperes and power-factor, and is therefore a measure of the actual power.

The **shifting nature of the field produced** can be shown by reference to Figs. 512 and 513. The dotted lines in Fig. 512 show the main paths of the magnetic flux produced by the two windings; the directions, however, constantly reversing owing to the alternations of the current in the coils. Denoting the shunt and series pole tips by the letters shown in Fig. 512, Fig. 513 gives a clear statement of the relation of the fields

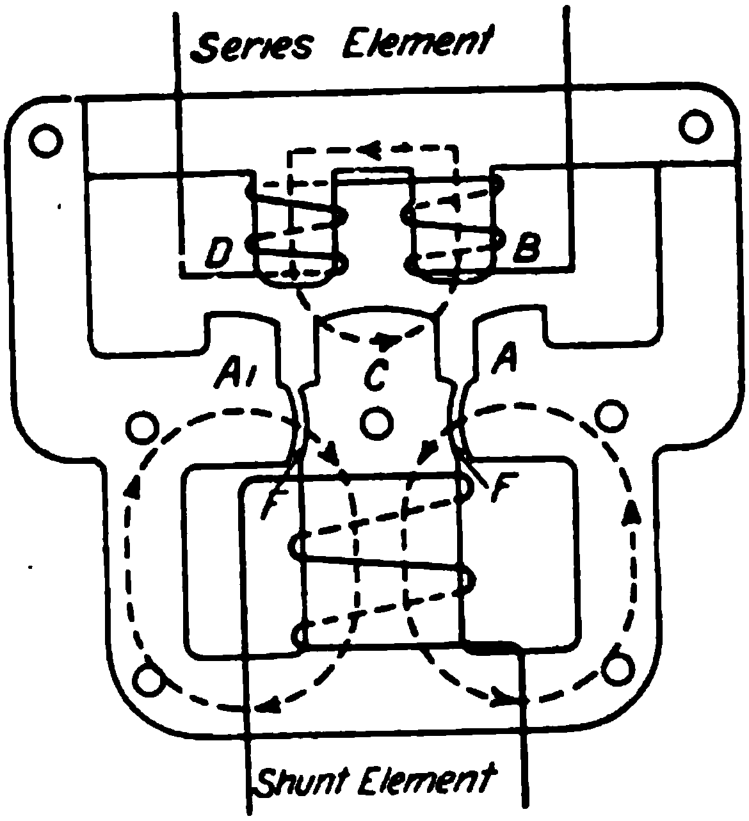


FIG. 512.—Diagram of Electromagnetic Circuits.

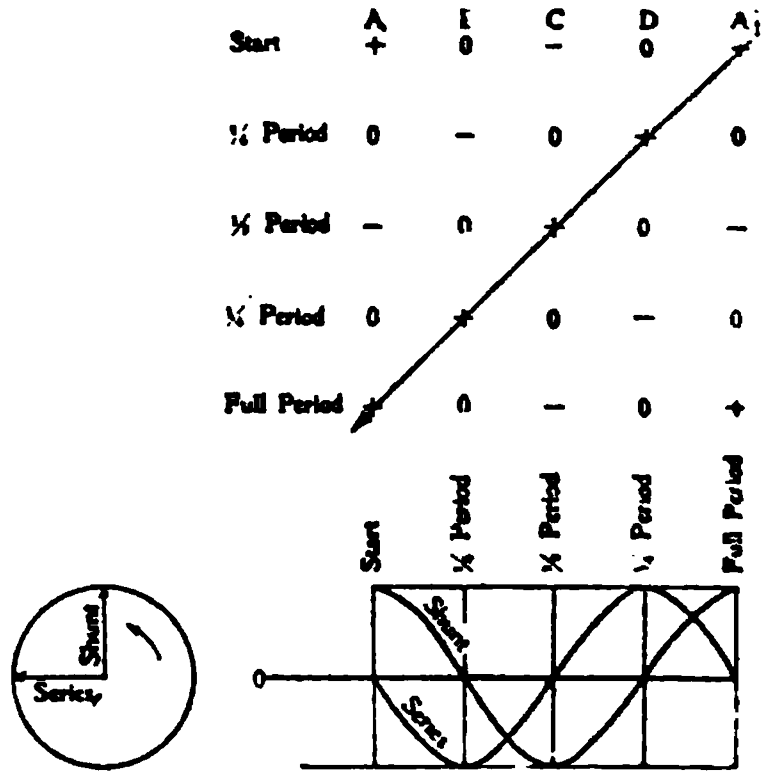


FIG. 513.—Diagram showing Rotation of Field.

at each ¼ period. The signs + and — represent the instantaneous values of the poles indicated. Thus, at one instant the pole tips A, C and A' of the potential coil are maximum +, — and +, respectively because the instantaneous value of the current is maximum, while the value of the series flux is zero. At ¼ period later the current in the potential circuit is zero, giving zero magnetic potential at the pole tips, while the series current has reached a maximum value, giving maximum — and + at the pole tips B and D. At the next ¼ period the current in the potential circuit is again maximum, but in a direction opposite to what it was at the beginning, making the pole tips A, C and A' —, + and —, respectively, while the series current again is zero. Continuing, the other relations of + and — poles shown in Fig. 513 is obtained. It will be

observed from the table that both the + and — signs move constantly in the direction from A′ to A, indicating a shifting of the field in this direction, the process being repeated during each cycle.

The **moving element** usually consists of a light metal disk, or cylinder, revolving through the air gap in which the rotating, or shifting, field is produced. This disk acts like the squirrel cage rotor of an induction motor. Currents are induced in it which combine with the rotating field to produce a torque or pull proportional to the power in the circuit. This torque is counterbalanced by that of the retarding element, so that, the speed is exactly proportional to the torque.

To make the wear on the bearing a minimum and thus give a long life to the watt-hour meter, the disk should be made as light as possible consistent with strength.

The **proper speed of the moving element** is determined by two factors, its effect on the life of the bearings and convenience in checking. Within the limits of permissible speed, that speed has been selected which renders calculation by a multiple of 5 or 25.

The **retarding element** acts as a load on the induction motor and enables the adjustment of its speed to normal limits. In order that the speed shall be proportional to the driving torque, which varies with the watts in the circuit, it is necessary that the torque of the retarding device be proportional to the speed. For this reason a short circuited constant field generator, consisting of a metal disk rotating between permanent magnet poles, has been generally adopted. The movement of the disk in the constant magnetic field generates an electromotive force between the inner and outer elements of the disk which is directly proportional to the speed. This electromotive force sets up eddy currents in the disk which consume the power passing through the meter coils. The generator, or retarding disk, may be the same disk used for the moving element, in which case the meter field acts on one edge while the permanent magnet acts on the edge diametrically opposite. This arrangement simplifies the number of parts and saves space and weight of moving element.

The **registering mechanism** comprises the dials and dial hands, and the train necessary to secure the required reduction in speed. This train is driven directly by the rotor, and therefore its friction should be low and constant. The dials should be easily read and should register directly in kilowatt-hours. If a register constant is used to reduce the reading to kilowatt-hours it should be some multiple of 10, to avoid errors in multiplication. By means of suitable gears in the meters this is accomplished.

The mounting frame and bearings have an important influence on the

accuracy of the meter, as it is in the bearings where most of the friction in the meter occurs.

The **bearings** used in the Westinghouse Type C watt-hour meters are shown in cross-section in Fig. 514. The lower bearing consists of a steel ball resting between two sapphire cup jewels, one fixed in the end of the bearing screw and the other mounted in a removable sleeve on the end of the shaft. Owing to the minute gyrations of the shaft the ball has a rolling action.

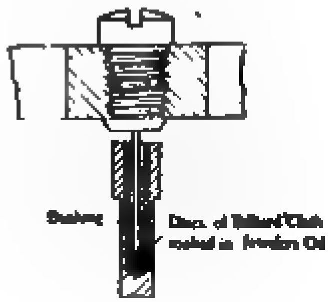


FIG. 514.—Cross-section of Bearings of Type C Watt-hour Meters.

The upper bearing is only a guide bearing to keep the shaft in a vertical position, and is subject to virtually no pressure. It consists of a steel pin fastened to a removable screw and projecting down into a bushing in a recess drilled in the shaft. The bottom of this recess is filled with billiard cloth saturated with watch oil. A film of oil is maintained around the pin by capillary action

Initial friction is unavoidable in any meter construction, but can be compensated for. A change in the initial friction, however, due to wear of bearings, makes readjustment necessary, therefore, a friction compensator is required to overcome the initial friction of the moving parts. It is apparent that if this initial friction were not compensated

for, some of the driving torque of the watt-hour meter would be used in overcoming it and the meter would not rotate at very light load. This would render the registration inaccurate on light loads.

The **friction compensation,** or **light load adjustment,** in the Type C meters is accomplished by slightly unbalancing the two legs of the shunt magnetic circuit. To do this a short circuit loop is placed in each air gap, and means are provided for adjusting the position of the loops so that one loop will enclose and choke back more of the flux than the other loop, and thus produce a slight rotative torque. It will be noted that this torque depends on voltage alone, which is practically constant, and is entirely independent of the load.

Adjustment is accomplished by means of either of two screws. Each of these screws has a knurled and slotted head and makes micrometer adjustment possible. It is clamped when adjusted by means of a set screw.

The **power-factor adjustment** is necessary to make the phase angle between the shunt and series field components exactly 90 degrees with unity power-factor in the metered circuit. Owing to the resistance and iron loss in the potential circuit, that field is not shifted quite 90 degrees with respect to the voltage. However, exact quadrature is necessary to make the strength of the resultant field, and consequently the rotor speed, proportional to the power-factor, as explained in the discussion of the field producing element.

The power-factor adjustment usually consists of a short circuited loop enclosing part or all of the field flux produced by the current in the potential coil. This loop acts like the secondary of a transformer. This flux induces a current in it which, acting with the current in the potential coil, produces a slightly lagging field. By shifting the position or the resistance of the short circuited loop, the lag may be so adjusted that the potential field flux is in exact quadrature with the voltage.

This method may be better understood by referring to the vector diagram (Fig. 515).

OA represents the e. m. f. impressed on the potential winding.

OY represents the current through the potential winding, lagging with respect to the impressed e. m. f. due to the reactance of the potential coil.

YOA represents the angle less than 90 degrees, due to iron and copper losses in the potential circuit.

OS represents the voltage induced in the closed secondary which is approximately opposite in phase relation to the voltage of the potential circuit.

OC represents the current in the closed secondary, which is in phase with the voltage OS (the magnitude of OS and OC being exaggerated)

OX represents the magnitude and direction of the resultant field produced by the combined effect of the currents OY and OC.

By changing the position of the closed secondary, the magnitude of OC can be increased or decreased, thereby shifting the position of the resultant OX, to obtain the proper 90 degree phase relation with respect to OA, thus compensating the meter to register correctly under varying conditions of power-factor.

It should be noted, however, that this adjustment makes the watt-hour meter correct at, or near, one frequency only. This feature is not objectionable if reasonable accuracy is maintained within the limits of normal variation of frequency.

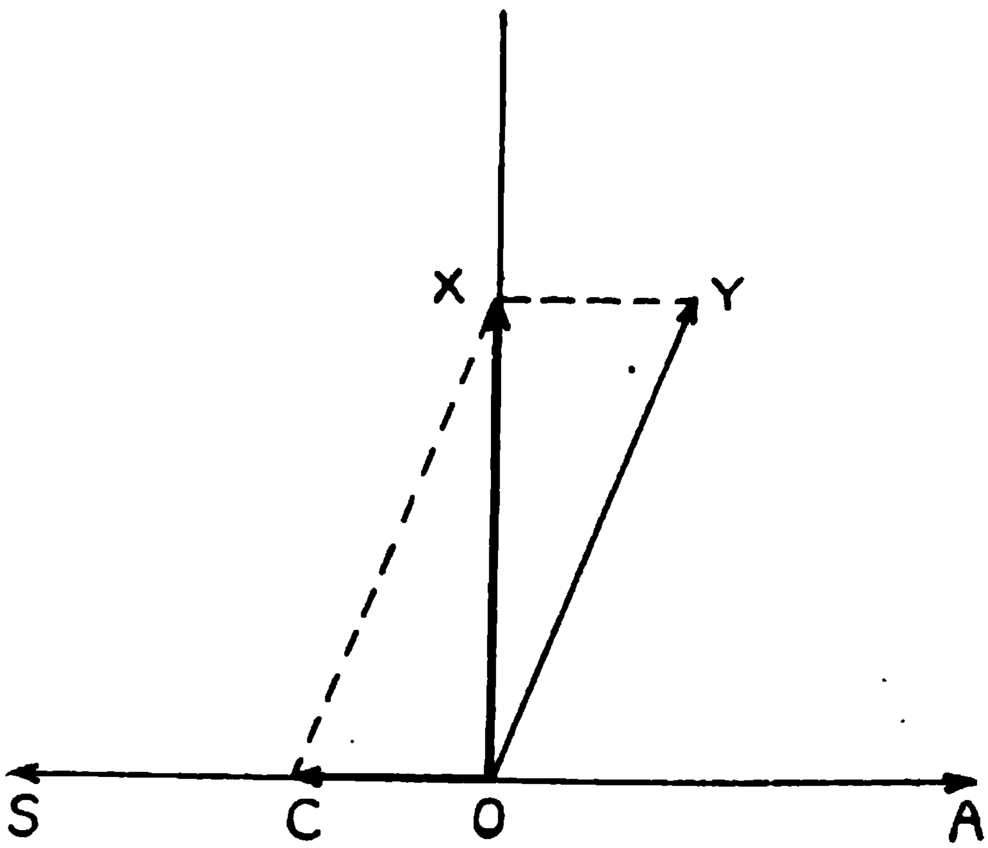


FIG. 515.—Vector Diagram for Westinghouse, Induction Watt-hour Meter.

A frequency adjustment is often desirable, particularly for systems operating at 133 cycles.

The case and cover should be absolutely dust and bug proof, to avoid damage to bearings, insulation and moving parts, and should of course be provided with means for sealing. Terminal chambers so arranged that the cover of the meter element need not be removed in connecting up are an important feature, particularly in meters that require no adjustment at installation, as they prevent entrance of dust into the main meter chamber and preserve the manufacturer's guarantee of initial accuracy. A window through which the rotation of the disk can be observed in checking should be provided for the same reason.

To measure the energy in alternating current circuits of high voltage,

or carrying heavy currents, it is necessary to use transforming devices, as without them the meter would have to be very large in order to have sufficient carrying capacity and insulation. The function of watt-hour meter transformers, is, therefore, to reduce the currrent and voltage to values that can be conveniently handled in watt-hour meters. When transformers are used, slight errors in accuracy are introduced, but with well-designed transformers these errors are small.

Description of Various Types

Round Type

Single-phase, Two-wire: The electromagnet of this type of meter is made up with one current coil for the current element and a potential coil in two sections with an impedance coil in series for the potential element.

Full load adjustment is made by moving the permanent magnets from, or toward the disk shaft. Moving the magnets from the shaft increases the speed of the meter. Moving the magnets toward the shaft decreases the speed of the meter.

The light load adjustment is made by varying the resistance of a short circuited coil on the right hand side of the electromagnet.

Power-factor adjustment is made by varying the resistance of a small coil on the left side of the electromagnet.

The terminals are on the back of the meter.

Single-phase, Three-wire: This meter is similar to the two-wire. The three-wire circuit measurement is obtained by means of a three-wire current transformer.

Polyphase Round Type: This is a two element (two disk—single shaft) meter. The individual electromagnets and their adjustments of this meter are the same as for the single-phase meter. The terminals are on the back of the meter.

The Westinghouse Round Type watt-hour meter was designed for house service for use upon alternating current, two and three-wire;—two-wire, polyphase, in capacities of 5, 10, 20, 40 and 80 amperes, 100, 200, and 400 volts; three-wire, in capacities of 5, 10, 20 and 40 amperes, 100-200, 200-400 volts; the single-phase meter being produced in June, 1898, and the polyphase in July, 1899. The diameter of the current terminals is 0.360 inches (Figs. 516 and 517).

Type A

Single-phase, Two-wire: The electromagnet is made up of one current coil for the current element—a potential coil in two sections with an impedance coil in series for the potential element.

FIG. 516.—External View of Westinghouse, Round Type, Single-phase, Induction Watt-hour Meter.

FIG. 517.—External View of Westinghouse, Round Type, Polyphase, Induction Watt-hour Meter.

Full load adjustment is made by varying the position of the permanent magnets the same as in the Round Type meters.

Light load adjustment is made by the movement of a slide resistance which is located on the electromagnet near the bottom of the meter.

The power-factor adjustment is made by varying the resistance of a short circuited coil on the left hand side of the electromagnet.

Single-phase, Three-wire: This meter is similar to the two-wire with the exception of the current winding, which consists of two separate, but interlaced coils.

Full load, light load and power-factor adjustments are the same as for the two-wire meter.

The meter has four terminals located in a separate terminal chamber at the top of the meter.

Single-phase, Three-wire Meter (Three-wire Current Transformers): This meter is similar to a two-wire meter with the exception that measurements of the three-wire circuit is obtained by the use of a three-wire current transformer.

Polyphase: This is a two element (two disk, single shaft) meter similar in appearance to the Round Type polyphase. The individual magnets with their adjustments are similar to the electromagnets of the single-phase meter.

The meter has six terminals—three per element located on the back of the meter.

The Westinghouse Type A watt-hour meter was designed for house service for use upon alternating current, two and three-wire; the two-wire polyphase in capacities of 5, 10, 20, 40 and 80 amperes, 100-200 and 400 volts; the three-wire in capacities of 5, 10, 20 and 40 amperes, 100-200, 200-400 volts; the single-phase meter being produced in January, 1903, and the polyphase meter in May of the same year. The diameter of the current terminals is 0.330 inches (Figs. 518 and 519).

Type B

Single-phase, Two-wire: The electromagnet of this meter consists of the current coil mounted on two poles, one half the winding on each pole and a potential coil mounted on a single pole. No impedance coil is used in the potential circuit.

Full load adjustment is made by varying the position of the permanent magnets. Moving the magnets away from the disk shaft decreases the speed of the meter. Moving the magnets toward the disk shaft increases the speed of the meter.

FIG. 518.—Westinghouse, Type A, Single-phase, 2-wire, Induction Watt-hour Meter.

FIG. 519.—External View of Type A, Westinghouse, Single-phase, 3-wire, Induction Watt-hour Meter.

circuit loop located in one of the leakage gaps of the potential electromagnet.

Power-factor adjustment is obtained by varying the position of a short circuit loop placed over the tip of the potential pole.

The meter has four terminals located in the terminal chamber at the top.

Single-phase, Three-wire: These are similar to the two-wire, except that the current coil is divided into two interlaced and independent circuits (Fig. 520).

FIG. 520.—Westinghouse, Type B, Single-phase, 2-wire, Induction Watt-hour Meter.

Prepayment: The meter element is the same as that for the regular Type B meter.

The prepayment mechanism is so arranged that when the coin is deposited in the meter it is indicated on the large dial. When the power paid for has been consumed a contact operated through a small differential gear is closed and the service discontinued by an electrically operated switch (Fig. 521).

The Westinghouse Type B and prepayment watt-hour meters were designed for house service for use upon alternating current, two and three-wire, single-phase; the two-wire Type B in capacities of 5, 10, 20, 40 and 80 amperes, 100, 200 and 400 volts; the three-wire Type B in capacities of 5, 10, 20 and 40 amperes, 100-200, 200-400 volts, and were produced in December, 1905. The diameter of the current terminals is

0.191 inches from 5 to 20 amperes capacity, and 0.315 inches from 40 to 80 amperes capacity. The two-wire prepayment type was built in capacities of 5, 10, 15 and 20 amperes, 100 and 200 volts, and the

FIG. 521.—Westinghouse, Type B, Prepayment, Single-phase, 2-wire, Induction Watt-hour Meter.

three-wire in capacities of 5, 10, 15 and 20 amperes, 100-200 volts. They were produced in January, 1906. The diameter of the current terminals is 0.191 inches.

Type C

Single-phase, Two-wire; Plain and Sub A: The electromagnet consists of a current coil mounted on two poles, one-half the winding on each pole and a potential coil mounted on a single pole. No impedance coil is used in the potential circuit. The iron laminations in the current winding are not interlaced with the laminations of the potential winding.

Full load adjustment is made by varying the position of the perma- magnets. Moving the magnets away from the disk shaft decreases

Ampere: These meters are the same as the two-wire, except that the current winding is divided into two interlaced and independent coils.

Later productions of Sub F are provided with an extra potential terminal in the terminal chamber, the purpose of which is to facilitate testing.

Single-phase, Two-wire; Sub E and F, 100 to 300 Ampere: Electromagnet and its adjustments are similar to that of the low capacity meter. The current and potential laminations are not interlaced. The meter

FIG. 523.—Westinghouse, Type C, Sub B, C, D, E and F, Single-phase, 2-wire, Induction Watt-hour Meter.

has three terminals leading from the top of the case. The middle lead is a potential lead, which in service is connected to the other side of the line.

Single-phase, Three-wire; Sub E and F, 60 to 150 Ampere: The electromagnet is similar to the two-wire heavy current meter. The current coils are independent of each other, are not interlaced, and are provided with special laminations which are interlaced with the laminations of the potential coil.

The meter has five terminals extending from the top of the meter. The potential coil is wound for placing across the outside lines of the -wire circuit. The middle lead is one end of the potential coil ht out for test purposes.

Polyphase; Plain, 5 to 80 Ampere: This is a two element (two disk, one shaft) meter. The individual electromagnets with their adjustments are the same as for the single-phase meter, Type C, plain and Sub A. The meter has three terminals per element—two on the right side and one on the left. Terminals are in a separate terminal chamber recessed in the sides of the case (Fig. 524).

Fig. 524.—Westinghouse, Type C, Polyphase, Induction Watt-hour Meter

Polyphase; Sub A and B, 5 to 80 Ampere: This is a two element (two disk, one shaft) meter. The electromagnets and their adjustments are the same as for the single-phase Sub D to F—5 to 80 ampere meters. The meter has side terminal chambers (Fig. 525).

Polyphase; Sub A and B, 100 to 300 Ampere: The electromagnets and their adjustment are the same as for the electromagnets of the low capacity meters with the exception that the laminations in the current and potential coils are not interlaced. The terminal leads are on the sides, two current terminals on each side and two voltage, or potential, terminals on the right side.

Polyphase; Plain, Sub A and B with Current and Voltage Transformer: These meters are similar to the low capacity 5-80 amperes

polyphase meters, except the voltage winding is entirely independent of the current terminals. The meters have four terminals per element.

Three-phase, Four-wire; Sub A and B, 5 to 40 Ampere: The electro-

Fig. 525.—Westinghouse, Type C, Sub A and Sub B, Polyphase, Induction Watt-hour Meter.

magnets of this meter are the same as the electromagnets of the polyphase, Sub A and B, 5 to 80 amperes, except that there is an additional interlaced current winding on each element. These additional windings on each element are connected in series forming the current winding

for the third current line. The voltage, or potential, coil of each electromagnet is wound for the voltage between outside wire and neutral or fourth wire. The meter has seven terminals.

Three-phase, Watt-hour Meters, with Current and Voltage Transformers for Three-phase, Four-wire Circuits: This meter is the same as the regular polyphase meter for transformer use. The three-phase measurement is obtained by the use of three current transformers and two voltage transformers.

The Westinghouse Type C watt-hour meter was designed for house service for use upon alternating current, two-wire single-phase, and polyphase, in capacities of 5, 10, 15, 20, 30, 40, 60, 80, 100, 120, 150, 200 and 300 amperes, 100, 200, 400 and 500 volts, the former being produced in November, 1906, and the latter in February, 1906. The three-wire single-phase meter was built in capacities of 5, 10, 15, 20, 30, 40, 60, 80, 100, 120 and 150 amperes, 100-200, 200-400 volts, in November, 1906. The diameter of the current terminals for the two-wire single-phase meter is: 5 to 15 amperes, 0.191 inch; 20 amperes, 0.213 inch; 30 to 80 amperes, 0.315 inch; 100 to 150 amperes, $\frac{9}{16}$ inch; 200 to 300 amperes, 0.94 inch. For the three-wire single-phase it is: 5 to 15 amperes, 0.191 inch; 20 amperes, 0.213 inch; 30 to 80 amperes, $\frac{5}{16}$ inch; 100 to 150 amperes, $\frac{9}{16}$ inch. For the polyphase it is: 5 to 40 amperes, 0.212 inch; 60 to 80 amperes, $\frac{3}{8}$ inch; 100 to 200 amperes, $\frac{7}{16}$ inch; 150 to 200 amperes, $\frac{23}{32}$ inch; 300 amperes, 0.76 inch.

Type OA

Single-phase, Two-wire; Top Terminal: The electromagnet of this meter is in general similar to that of the Type C. The shape of the laminations is somewhat different and the amount of iron is less.

The full load adjustment is similar to that in the Type C.

The light load adjustment is made by the movement of a micrometer screw on the right-hand side of the meter.

The power-factor adjustment is obtained by the use of a short circuit loop, on the tip of the voltage, or potential, electromagnet.

The meter has four terminals in a terminal chamber at the top of the meter (Fig. 526).

Single-phase, Three-wire; Top Terminal: This meter is similar to the two-wire with the exception that the current coil is divided into two independent interlaced windings.

Single-phase, Two-wire; Bottom Terminal: This meter is similar to the two-wire top terminal meter except the terminal chamber is at the bottom of the meter case (Fig. 527).

FIG. 526.—Westinghouse, Type OA, Single-phase, 2-wire, Induction Watt-hour Meter, with Top Terminals.

to the three-wire top terminal meter except the terminal chamber is at the bottom of the meter case.

Note: All references to "left hand" and "right hand" hold true when looking at the front of the meter.

The Westinghouse Type OA watt-hour meter was designed for house

FIG. 527.—External View of Type OA, Westinghouse, Single-phase, 2-wire, Induction Watt-hour Meter, with Bottom Terminals.

service for use upon alternating current, two and three-wire, single-phase circuits, in capacities of 5 and 10 amperes; two-wire, 100 and 200 volts; three-wire, 100-200 volts; and was produced in April, 1911. The diameter of the current terminals is 0.191 inch.

On all **meters** full load **adjustment** is made by moving the permanent magnet in or out from the disk shaft.

Weakening of the drag magnets tend to make the meter run fast.

Defects that would tend to make the meter run slow would be any mechanical interference between rotating parts and stationary parts, foreign matter in the air gap of the drag magnets, defective bearings or gear trains, or short circuited current coil.

For the Round Type and Type A the light load adjustment is made by varying the amount of resistance in a short circuited coil mounted on a portion of the potential electromagnet.

For Types B, C and OA the light load adjustment is made by varying the position of the short circuited loops located in air gaps of the voltage electromagnet.

Defects that would tend to make the meter run fast are short circuits in the portion of the current coil on the left-hand current pole (left-hand, looking at face of meter), open circuit in the left-hand light load adjuster loop.

Defects that would tend to make the meter run slow are, short circuit in the portion of the current coil on the right-hand current pole (right-hand, looking at the face of the meter) and open circuit in the right-hand light load adjuster loop.

The standard formula for testing Westinghouse alternating current Watt-hour meters when using indicating standards and stop watches, is,

$$\text{watts} = \frac{R \times K}{T} \text{ in which:}$$

R = Number of complete revolutions in time T.
T = Time in seconds required for revolutions R.
K = Constant.

The constant K varies with different types and capacities as outlined below, and is the same as "K_t" or "Test Constant." Tables in Chapter XV give the gear ratios, constants and test formulas.

The overload capacity of these watt-hour meters is 50 per cent.

Instructions are pasted on the back of the meter and on the inside of the terminal cover.

The following tabulation gives additional information pertaining to 60 cycle watt-hour, house service meters:

	Round Type		Type A		Type B	Prepay	Type C		Type OA
	S.P.	P.P.	S.P	P.P.	S.P.	S.P.	S.P.	P.P.	S.P.
Full load, Rev. per min.	50	50	50	50	25	25	25	25	25
Average limits full load torque (mm-g.)	10–12	20–24	10–12	20–24	21–24	21–24	38–42	76–84	34–38
Average limits wt. of mov. elem. (g.)	15–16	30–32	15–16	30–32	15–16	15–16	15–16	30–32	15–16
Average ratio torque to wt.	.71	.71	.71	.71	1.45	1.45	2.58	2.58	2.32
Average limits series drop (volts)	.2–.3	.2–.3	.2–.3	.2–.3	.2–.3	.2–.3	.25–.35	.25–.35	.25–.35
Average limits series loss (watts)	.9–1.1	1.8–2.2	.9–1.1	1.8–2.2	.7–.9	.7–.9	.7–1.0	1.4–2.0	.65–.85
Average limits shunt loss (watts)	1.5–1.8	3–3.6	1.8–2.1	3.6–4.2	2.5–2.8	2.5–2.8	1.5–1.8	3–3.6	1.4–1.8
Average limits shunt circuit P. F.	27–30	27–30	27–30	27–30	18–20	18–20	18–20	18–20	16–19
Average limits temp. coef. per deg. C.	.05–.07	.05–.07	.05–.07	.05–.07	.05–.07	.05–.07	.05–.06	.05–.06	.05–.06
Date of production	June 1898	July 1899	Jan. 1903	May 1903	Dec. 1905	Jan. 1906	Nov. 1906	Feb. 1906	April 1911

Westinghouse Continuous Current Watt-hour Meters

Westinghouse continuous current watt-hour meters, the principles of which are explained in Chapter III, are essentially motor generators provided with registering mechanism.

Descriptions of Various Types

Two-wire Meter, Plain, 5-100 *Amperes*

The current winding is divided into two independent coils located on opposite sides of the armature, one coil in the positive and the other coil in the negative side of the line circuit. The voltage circuit in the meter consists of a friction compensation coil, an armature, and a resistance. The friction compensation potential coil end of the voltage circuit is connected to the negative terminal of the line circuit and the resistance end of the voltage circuit is connected to the positive terminal of the line circuit.

The adjustment for light load is obtained by moving the friction compensation coil in toward or out from the armature shaft. The disk and permanent or drag magnets, are at the bottom of the meter.

The terminals are on the sides, near the top. The line terminals are on the left-hand side of the meter case. The lower bearing of this meter has a sapphire jewel and ball bearing (Fig. 528). Instructions for metermen are placed on the inside of the cover of all plain meters (Fig. 529).

Three-wire Meter, Plain, 5-100 *Amperes*

This meter is similar to the two-wire meter. The current winding is divided into two independent coils, one in each of the outside lines of the three-wire circuit. The resistance end of the voltage circuit is brought to a separate terminal for making connection to the neutral line outside of the meter.

Two-wire Meter, Sub A, 5-75 *Amperes*

This is a commutator type meter. The current coils are connected to the positive side of the line circuit. The voltage circuit in the meter consists of a friction compensation coil, an armature, and a resistance. The friction compensation coil end of the voltage circuit is connected to the positive terminal of the line circuit and the resistance end of the voltage circuit is connected to the negative terminal of the line circuit.

The friction compensation coil has two movements;—one in and out from the armature shaft, the other up and down in a plane parallel to the armature shaft.

The disk and permanent or drag magnets are at the top of the meter
The terminals are on the sides, near the bottom, of the meter case
The line terminals are on the left-hand side (Fig 530).

FIG. 528.—Cross-section of Lower Bearing of Westinghouse, Continuous Current Watt-hour Meters.

The lower bearing of this meter has a sapphire jewel and ball bearing (Fig. 528).

Three-wire Meter, Sub A, 5-75 *Amperes*

This meter is similar to the two wire.

The current winding is divided into two independent coils, one for each of the outside lines of the three-wire circuit. The resistance end of the voltage circuit is brought to a separate terminal for making connection to the neutral line outside of the meter.

Two-wire Meter, Sub A, 100-450 *Amperes*

This meter is similar to the low capacity meter.

The positive side only on the line circuit is taken through the meter
The terminals are in the form of cables extending from the bottom of the meter case

Three-wire Meter, Sub A, 100-300 Amperes

This meter is similar to the low capacity three-wire meter.

The terminals are in the form of cables extending from the sides of the meter case.

FIG 529.—Westinghouse, Type DC, Plain, 2-wire, Continuous Current Watt-hour Meter.

The standard formula for testing Westinghouse Plain and Sub A continuous current watt-hour meters when using indicating instruments and stop watch is

$$\text{Watts} = \frac{R \times K_t}{T} \text{ in which}$$

R = Number of complete revolutions in Time T.
T = Time in seconds required for revolutions R.
K_t = Constant.

The constant K_t varies with the capacity of the meter. Tables in Chapter XV give the gear ratios, constants and test formulas.

FIG. 530 —Westinghouse, Type DC, Sub A, 2-wire, Continuous Current Watt-hour Meter.

The following applies to both the Plain and Sub A meters. The potential circuit coil consists of 800 turns of copper wire, three mils in diameter, having a resistance of 600 ohms. The series field, when carrying current at the rated capacity of the meter, produces 600 ampere-turns. The resistance of the potential circuit is 2,500 ohms per 100 volts.

Capacity in Amperes	Two-wire Meters Average Limits of Current Coil Circuit		Three-wire Meters Average Limits of Current Coil Circuit		Diameter Terminal Hole—Inches	
	Drop in Volts	Loss in Watts	Drop in Volts	Loss in Watts	Two-wire	Three-wire
5	1.4 –1.56	7.0–7.8	0.7 –0.78	7.0– 7.8	0.191	0.191
7.5	0.6 –0.73	4.5–5.5	0.3 –0.39	4.5– 5.5	0.191	0.191
10	0.5 –0.6	5.0–6.0	0.25 –0.30	5.0– 6.0	0.191	0.191
15	0.3 –0.37	4.5–5.5	0.15 –0.185	4.5– 5.5	0.191	0.191
25	0.2 –0.24	5.0–6.0	0.10 –0.12	5.0– 6.0	0.191	0.191
50	0.11 –0.13	5.5–6.5	0.05 –0.06	5.0– 6.0	3/8 (Plain); 0.345 (Sub A)	3/8
75	0.067–0.08	5.0–6.0	0.046 –0.053	7.0– 8.0	3/8 (Plain); 0.345 (Sub A)	3/8
100	0.050–0.06	5.0–6.0	0.042 -0.048	8.5– 9.5	7/16	7/16
150	0.046–0.053	7.0–8.0	0.028 –0.032	8.5– 9.5	9/16 (Sub A only)	9/16 (Sub A only)
200	0.040–0.048	8.0–9.5	0.0225–0.025	9.0–10.0	0.915 (Sub A only	0.915 (Sub A only)
300	0.026–0.032	8.0–9.5	0.021 –0.025	13.0–15.0	1.0 (Sub A only)	1.0 (Sub A only)
450	0.024–0.029	11.0–13.0			1.0 (Sub A only)	

At rated capacity the speed is 25 rev. per min. and the torque in mm-g. varies from 120 to 160. The weight of the moving element varies from 80 to 90 grams and the average ratio of weight to torque is 1.65. The loss in the potential circuit per 100 volts varies from 3.5 to 4.5 watts. The average limits of the temperature coefficient per degree C. are 0.09 to 0.12. These meters have an overload capacity of 50 per cent. Both types were produced in April, 1906.

Type CW-6

Two-wire Meter, 5-50 *Amperes*

The current coils are in the positive side of the line circuit. The voltage circuit of the meter consists of the armature and the friction compensation coil. The resistance necessary for the voltage circuit is contained in the friction compensation coil, a portion of the winding being reversed on itself. The armature end of the voltage circuit is connected to the positive terminal of line circuit; the friction compensation coil end of the voltage circuit is connected to the negative terminal of the line circuit.

The friction compensation coil has two movements, one in and out from the armature shaft, and the other up and down in a plane parallel to the armature shaft.

The disk and permanent or drag magnets are at the bottom of the meter.

The terminals are on the sides of the meter case.

The lower bearing of all standard Type CW-6 meters has a sapphire jewel and ball bearing (Fig. 528). Pivot bearings are supplied when desired. Instructions for metermen are placed on the inside of the cover and also on the back of the meter (Fig. 531)).

Three-wire Meter, 5-50 *Amperes*

This meter is similar to the two-wire.

The current winding is divided into two separate coils, one in each of the outside lines of the three-wire circuit. The friction compensation coil end of the potential circuit is brought to a separate terminal for connection to the neutral on the outside of the meter.

The standard formula for testing Westinghouse Type CW-6 continuous current watt-hour meters, when using indicating instrument and stop watch, is

$$\text{Watts} = \frac{3{,}600 \times K_t \times R}{S}, \text{ in which}$$

R = Number of revolutions.
S = Number of seconds required to make this number of revolutions.
K_t = Calibrating constant marked on meter disk.
3,600 = Number of seconds in one hour.

FIG. 531.—Westinghouse, Type CW-6, 2-wire, Continuous Current Watt-hour Meter.

Tables in Chapter XV give the gear ratios, constants and test formulas.

The potential circuit coil of this type of meter consists of 1,500 active and 400 inactive turns of copper wire three mils in diameter, having

a resistance of 1,500 ohms. The resistance of the potential circuit is 2,300 ohms per 100 volts.

The following tabulation is applicable to Type CW-6 meters only:

Capacity in Amperes	Two-wire Meters Average Limits of Current Coil Circuit		Three-wire Meters Average Limits of Current Coil Circuit		Diameter Terminal Holes—Inches	
	Drop in Volts	Loss in Watts	Drop in Volts	Loss in Watts	Two-wire	Three-wire
5	1.0 –1.14	5.0–5.7	0.5 –0.57	5.0–5.7	1/4	1/4
10	0.5 –0.57	5.0–5.7	0.25 –0.285	5.0–5.7	1/4	1/4
15	0.38–0.44	5.8–6.6	0.19 –0.22	5.8–6.6	1/4	1/4
25	0.22–0.25	5.5–6.3	0.11 –0.125	5.5–6.3	1/4	1/4
50	0.11–0.125	5.5–6.3	0.055–0.0625	5.5–6.3	3/8	3/8

At rated capacity the speed varies and depends upon the capacity of the meter in question. The speed of any particular meter of this type is determined from the constant marked on the disk. The following data is given by the manufacturers of this meter.

Full load torque	140 to 170 mm-g.
Weight of moving element	80 to 95 g.
Ratio of torque to weight	1.7
Loss per 100 volts in potential circuit	4 to 5 watts
Temperature coefficient per degree C............	0.09 to 0.13

These meters have an overload capacity of 50 per cent.

This meter was produced in May, 1912.

The internal and external connections for these types of watt-hour meters are given in Figs. 532 to 561, and the external dimensions in Figs. 561 to 570.

External and Internal Connection Diagrams

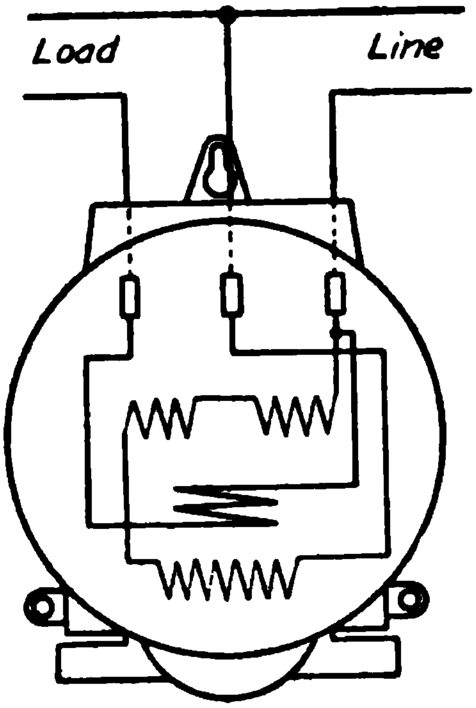


Fig. 532.—Single-phase, 2-wire, Round Type Only.

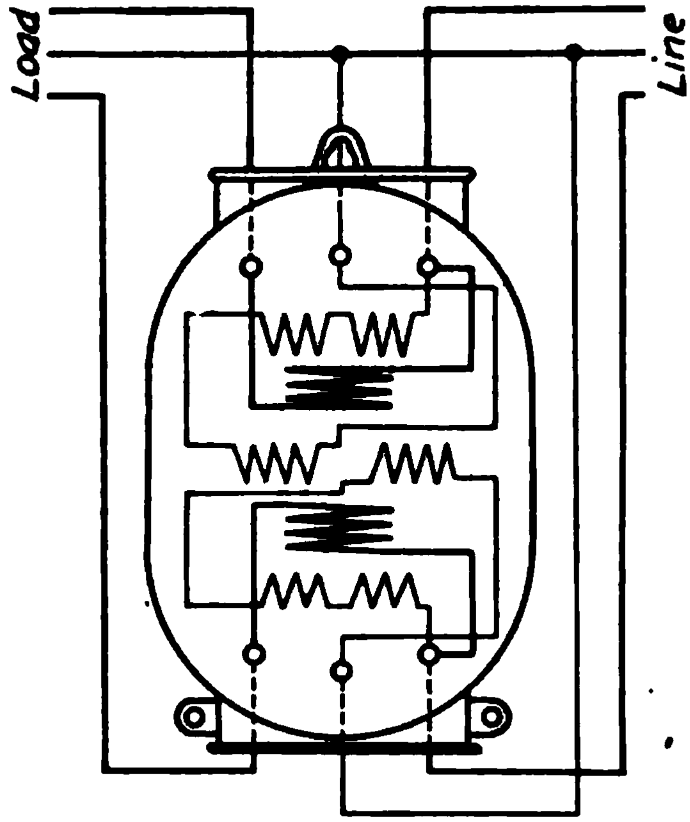


Fig. 533.—Polyphase, 3-wire, Round Type and Type A.

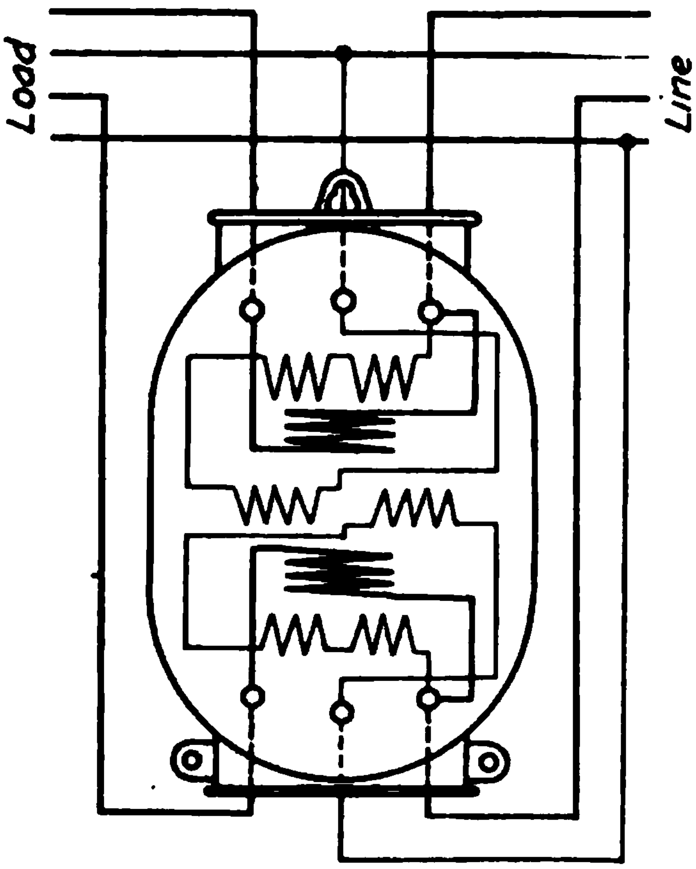


Fig. 534.—Two-phase, 4-wire, Round Type and Type A.

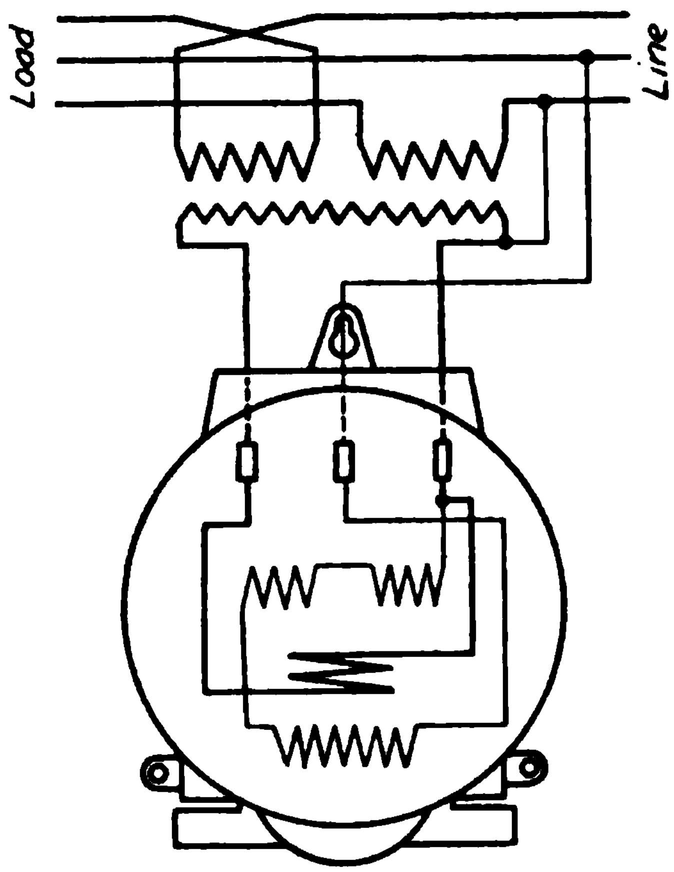


Fig. 535.—Single-phase, 3-wire, Round Type and Type A, both with 3-wire Transformer.

External Connections for Westinghouse, Round Type and Type A, Induction Watt-hour Meters.

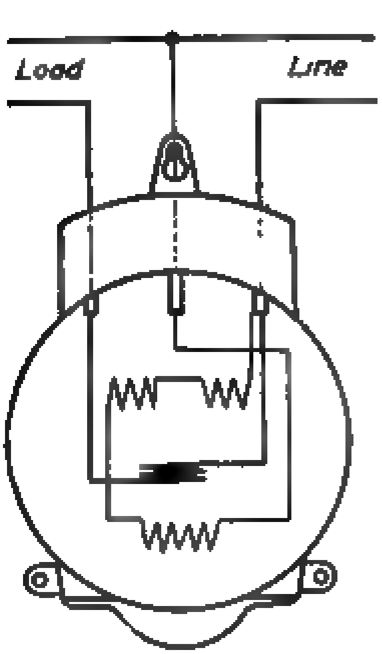


FIG. 536.—Single-phase, 2-wire, Type A

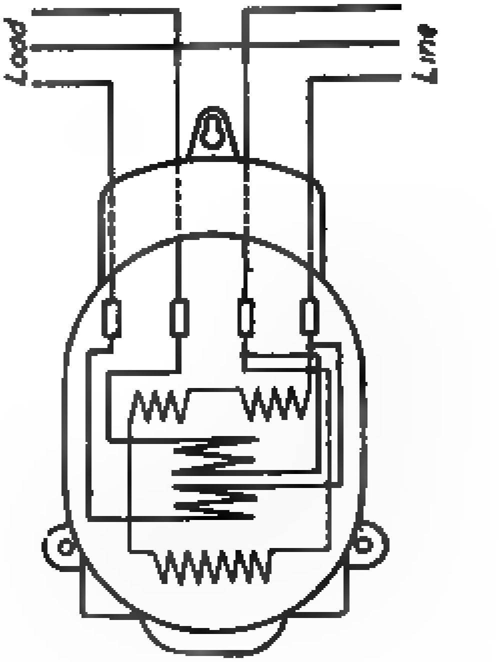


FIG. 537.—Single-phase, 3-wire, Type A

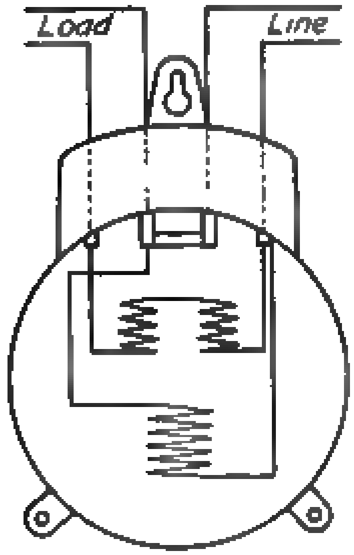


FIG. 538.—Single-phase, 2-wire, Types B, C, Sub B to F and OA, 5–80 Amperes

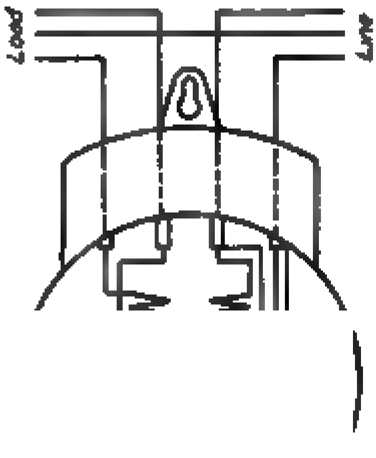


FIG. 539.—Single-phase, 3-wire, Type B. Type C, Sub B to F, 5–40 Amperes. Type C, Sub B to D, 80–120 Amperes. Type OA.

External Connections for Westinghouse, Single-phase, Induction Watt-hour Meters.

FIG. 540.—Single-phase, 2-wire, Prepayment, Type B.

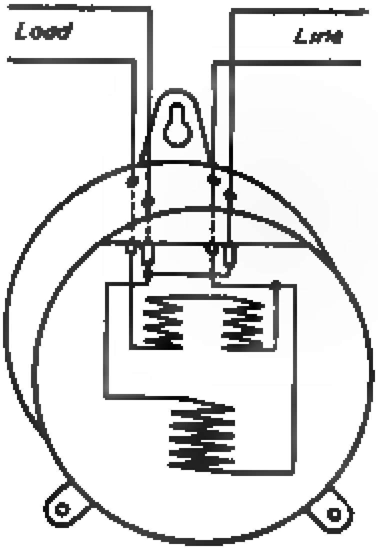


FIG. 541.—Single-phase, 2-wire, Type C, Plain and Sub A, 5–80 Amperes.

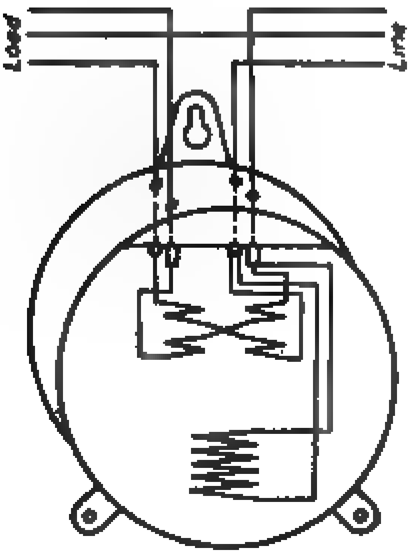


FIG. 542.—Single-phase, 3-wire, Type C, Plain and Sub A, 5–40 Amperes.

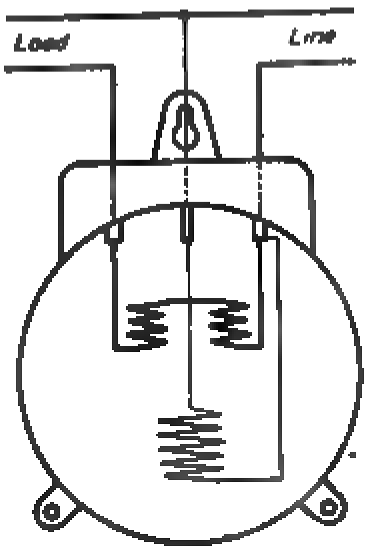


FIG. 543.—Single-phase, 2-wire, Type C, Sub E and F, 100–300 Amperes.

External and Internal Connections for Westinghouse, Types B and C, Induction Watt-hour Meters.

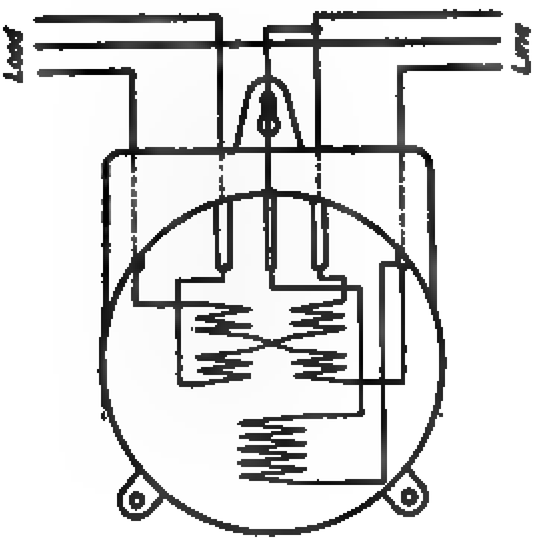


FIG. 544.—Single-phase, 3-wire, Type C, Sub E and F, 60–150 Amperes.

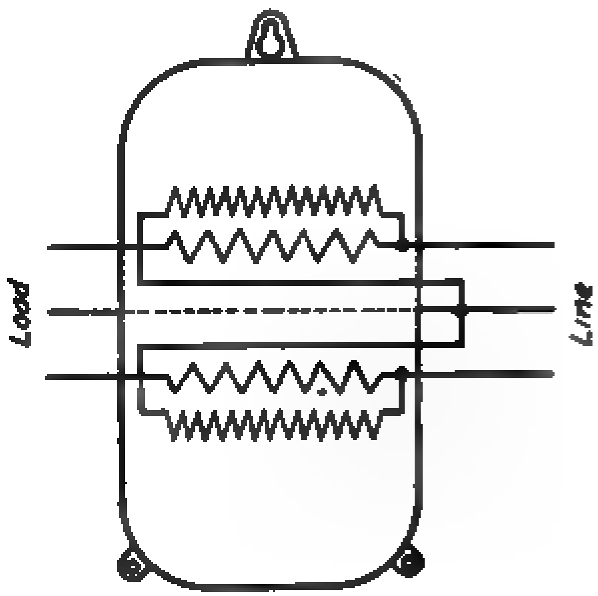


FIG. 545.—Polyphase, 3-wire, Type C, Sub A to C, 100–300 Amperes.

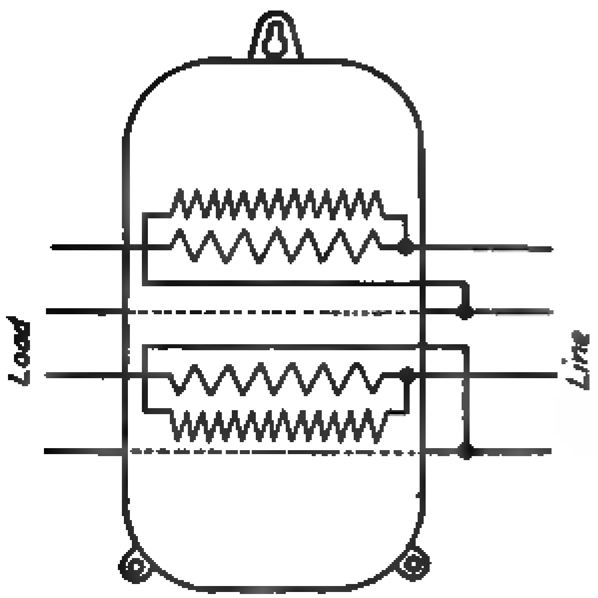


FIG. 546.—Two-phase, 4-wire, Type C, Sub A to C, 100–300 Amperes.

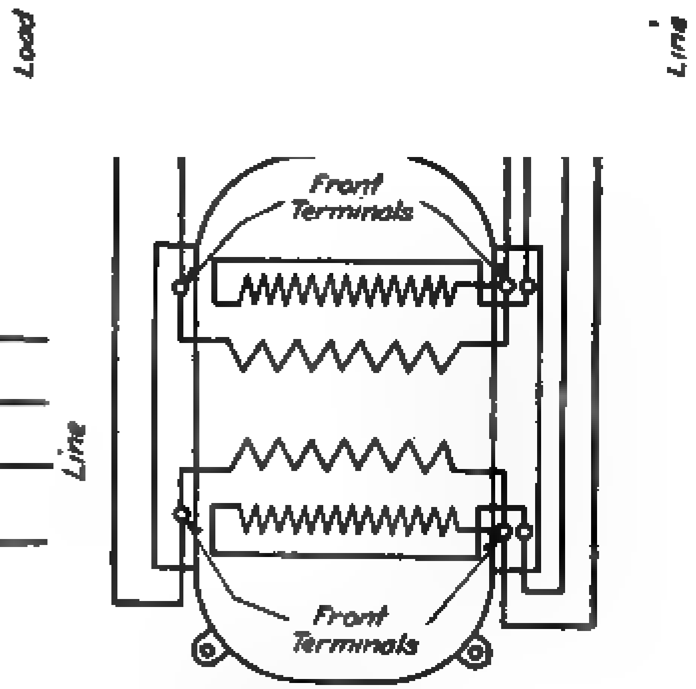


FIG. 547.—Two-phase, 4-wire, * Type C, Plain, 5–80 Amperes. Type C, Sub A and B, 5–80 Amperes.

* Type C, Plain, have the terminals recessed in the sides of the case.

External and Internal Connections for Westinghouse, Type C, Induction Watt-hour Meters.

Load

Line

FIG. 548.—Three-phase, 4-wire, Type C, Sub A and B, 5–40 Amperes.

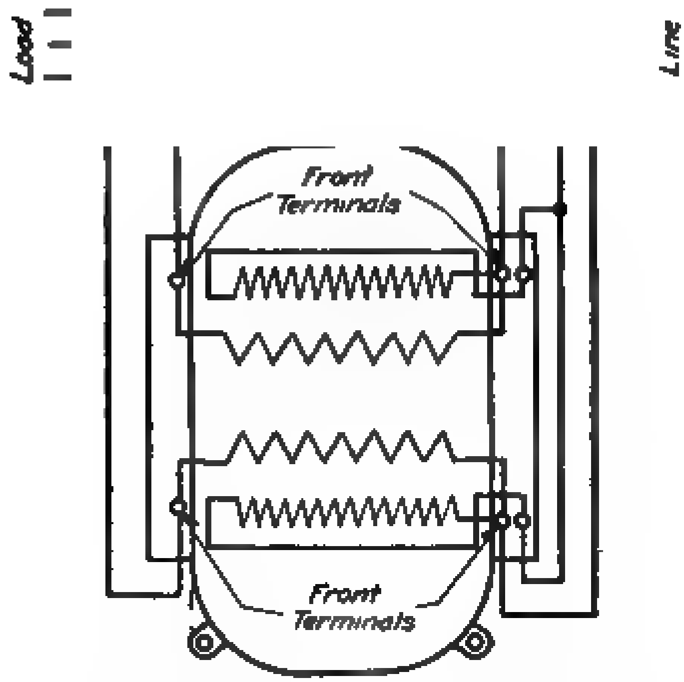


FIG. 549.—Polyphase, 3-wire, * Type C, Plain, 5–80 Amperes. Type C, Sub A and B, 5–80 Amperes.

* Type C, Plain, have the terminals recessed in the sides of the case.

External and Internal Connections for Westinghouse, Type C, Induction Watt-hour Meters.

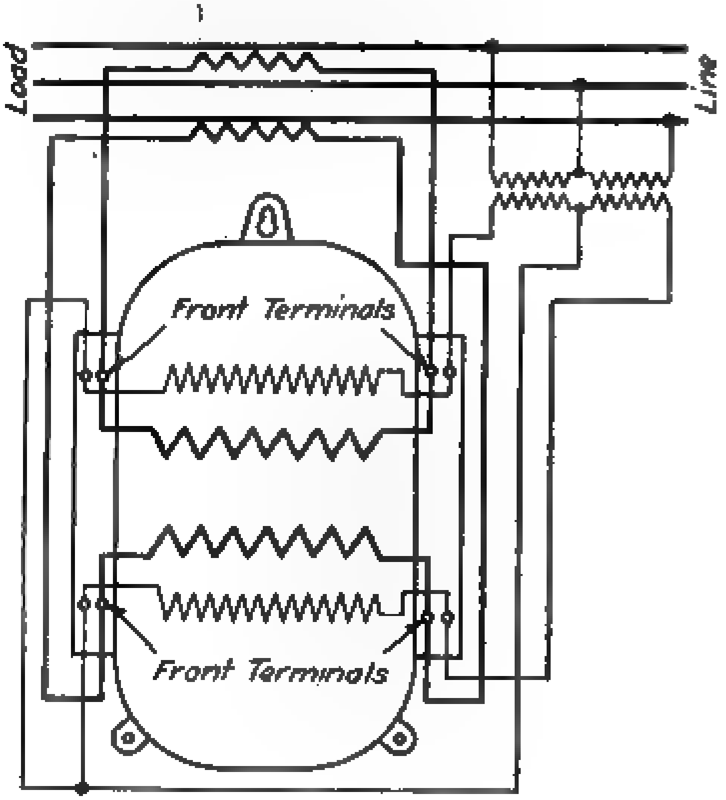


FIG 550.—Polyphase, 3-wire, with Current and Voltage Transformers. Type C, Plain, Sub A, Sub B

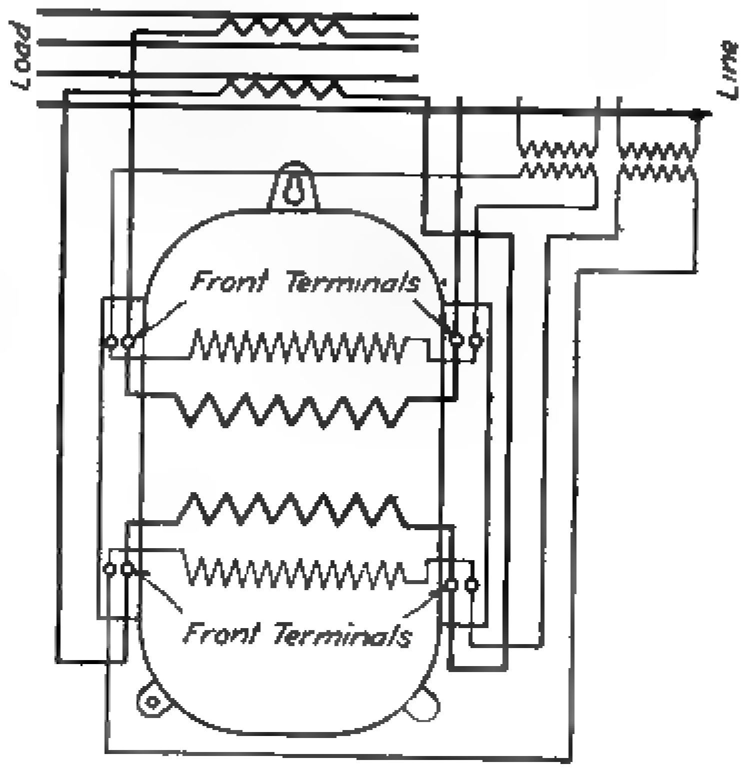


FIG 551.—Two-phase, 4-wire, with Current and Voltage Transformers. Type C, Plain, Sub A, Sub B.

External and Internal Connections for Westinghouse, Type C, Induction Watt-hour Meters.

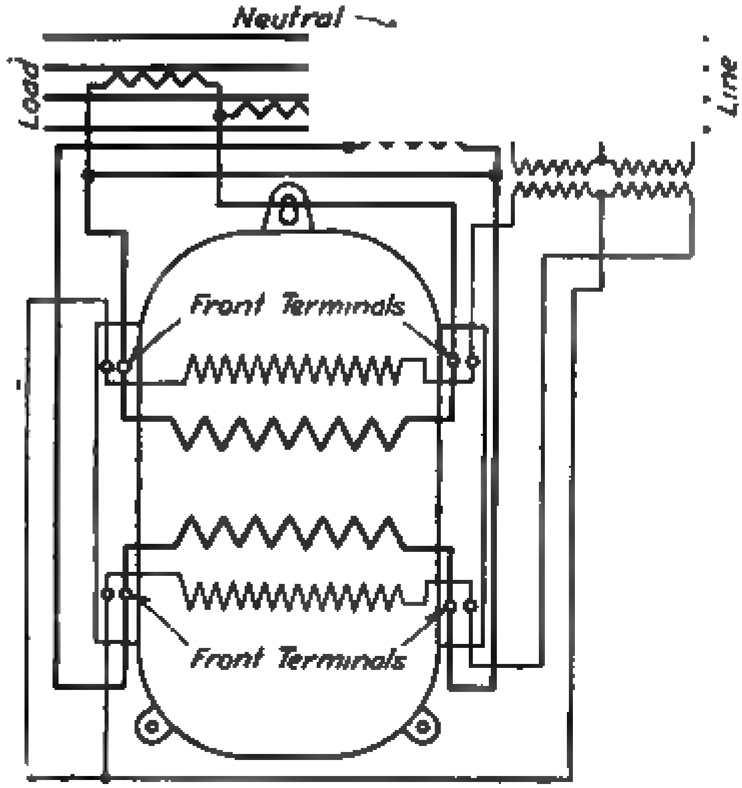


Fig. 552.—Three-phase, 4-wire, with Current and Voltage Transformers. Type C, Plain, Sub A, Sub B.

External and Internal Connections for Westinghouse, Type C, Induction Watt-hour Meter.

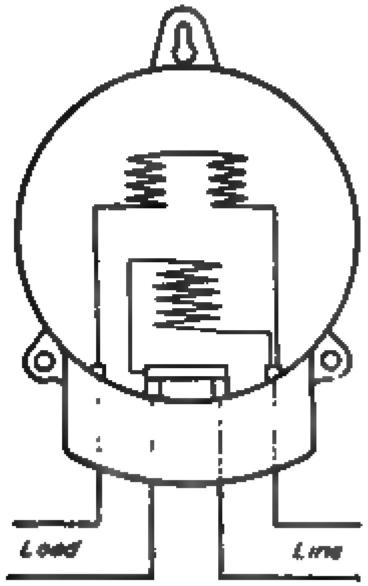


Fig. 553.—Single-phase, 2-wire, Bottom Terminals, Type OA.

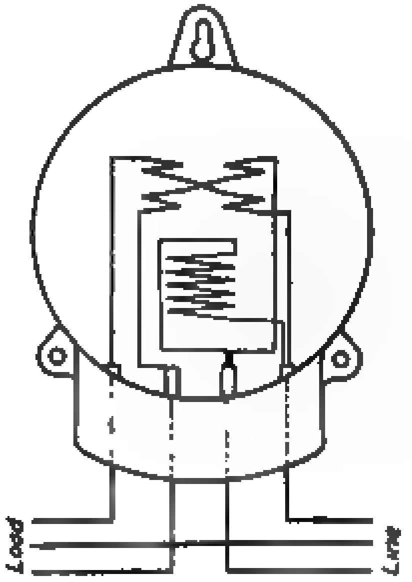


Fig. 554.—Single-phase, 3-wire, Bottom Terminals, Type OA.

External and Internal Connections for Westinghouse, Type OA, Induction Watt-hour Meter.

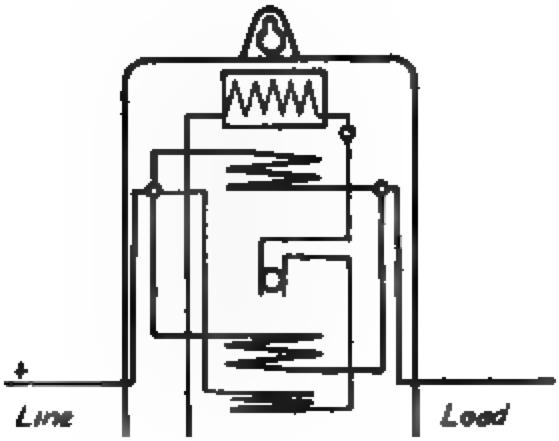


FIG. 555.—Continuous Current, 2-wire, Type DC, Sub A, 15-75 Amperes.

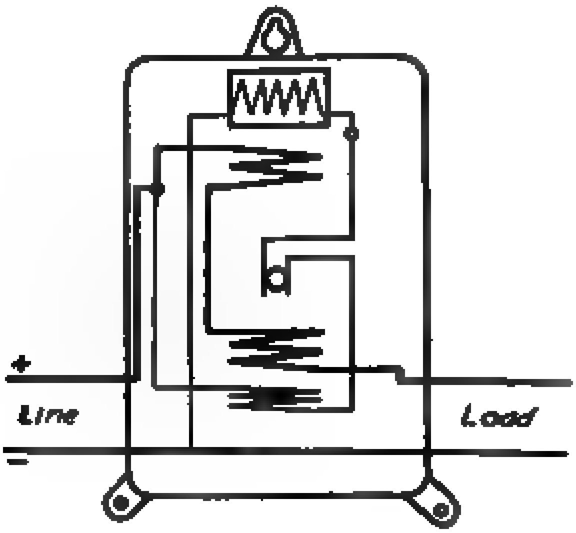


FIG. 556.—Continuous Current, 2-wire, Type DC–A, 5-75 Amperes.

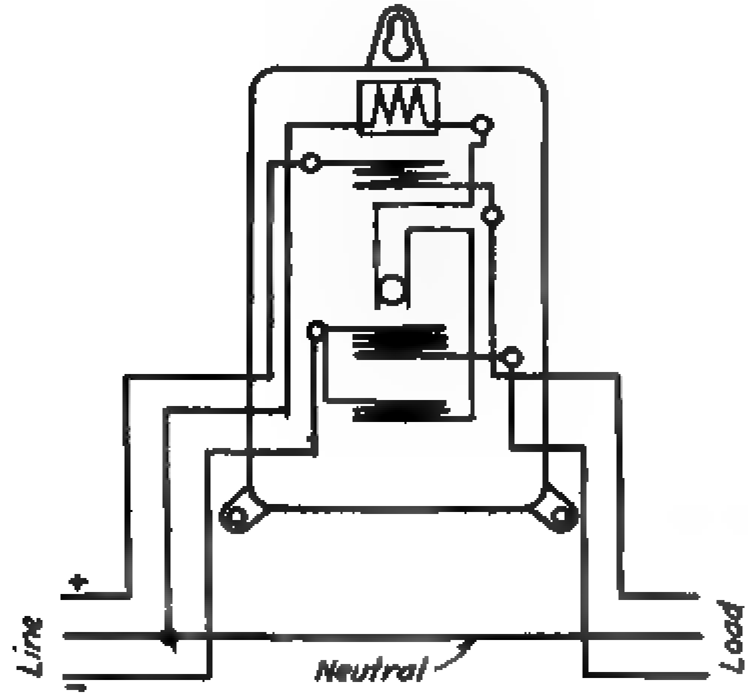


FIG. 557.—Continuous Current, 3-wire. Type DC, Sub A, 5-75 Amperes. Type DC, Sub A, 100-300 Amperes.

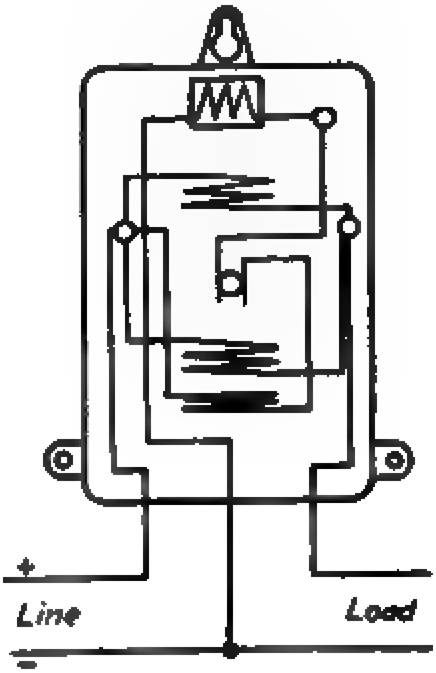


FIG. 558.—Continuous Current, 2-wire, Type DC, Sub A, 100-450 Amperes.

External and Internal Connections for Westinghouse, Continuous Current Watt-hour Meters.

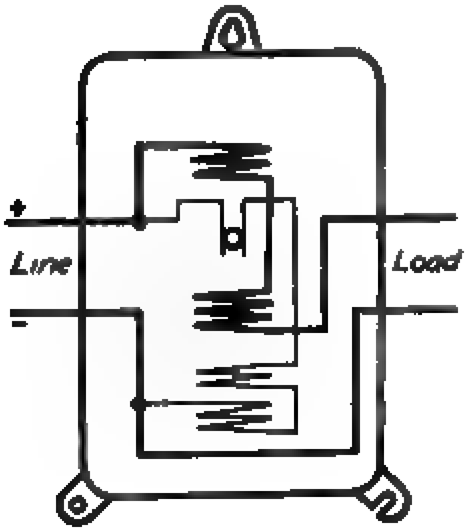


FIG. 559.—Continuous Current, 2-wire, Type CW-6, 5-15 Amperes.

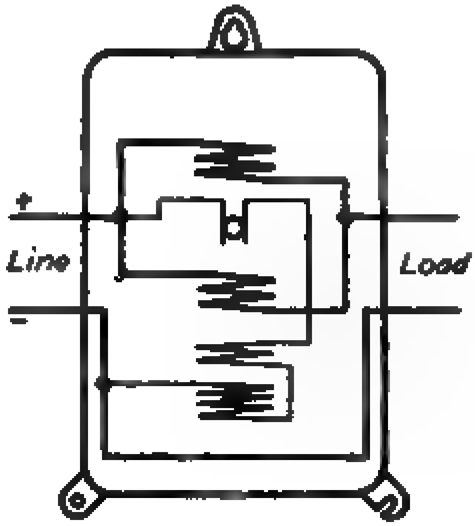


FIG. 560.—Continuous Current, 2-wire, Type CW-6, 25-50 Amperes.

FIG. 561.—Continuous Current, 3-wire, Type CW-6, 5-50 Amperes.

External and Internal Connections for Westinghouse, Continuous Current Watt-hour Meters.

External Dimension Diagrams

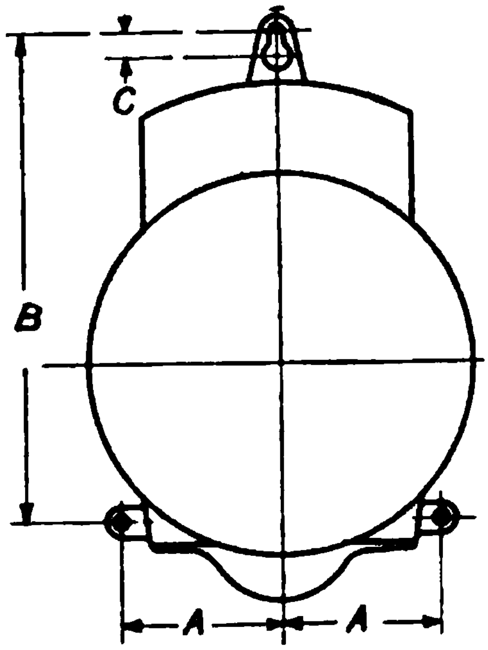


Fig. 562.—Dimensions of Westinghouse, Single-phase Watt-hour Meters.

Approximate Dimensions in Inches.

Type Meter.	Capacity Amperes.	A	B	C	Total Height.
Round, 2-wire......	5–80	2 ¾ in.	6 9/16 in.	7/16 in.	6 in.
A, 2-wire..........	5–80	2 ¾ in.	8 1/16 in.	7/16 in.	6 in.

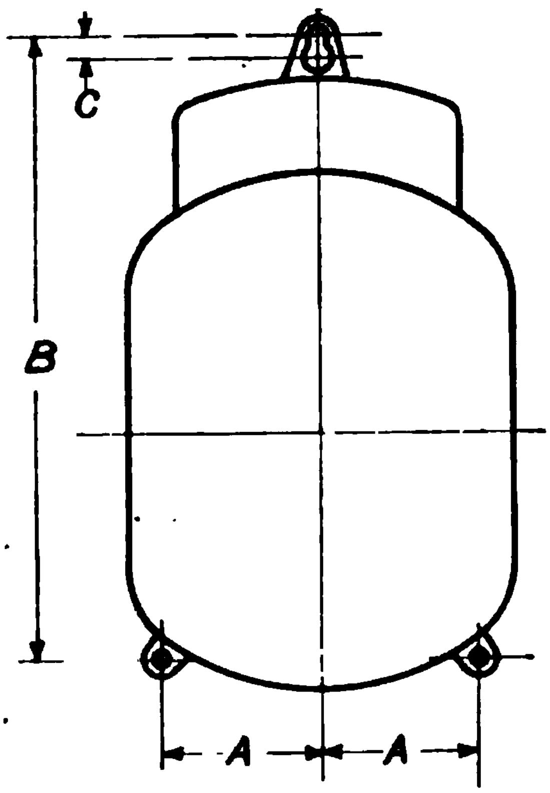


Fig. 563.—Dimensions of Westinghouse, Single-phase Watt-hour Meter.

Approximate Dimensions in Inches.

Type.	Capacity Amperes.	A	B	C	Total Height
B—Prepayment..... 2 and 3	5–20	2 7/8 in.	11 3/16 in.	7/16 in.	7 1/8 in
A -3-wire..........	5–40	2 3/4 in.	8 3/4 in.	7/16 in.	6 1/8 in

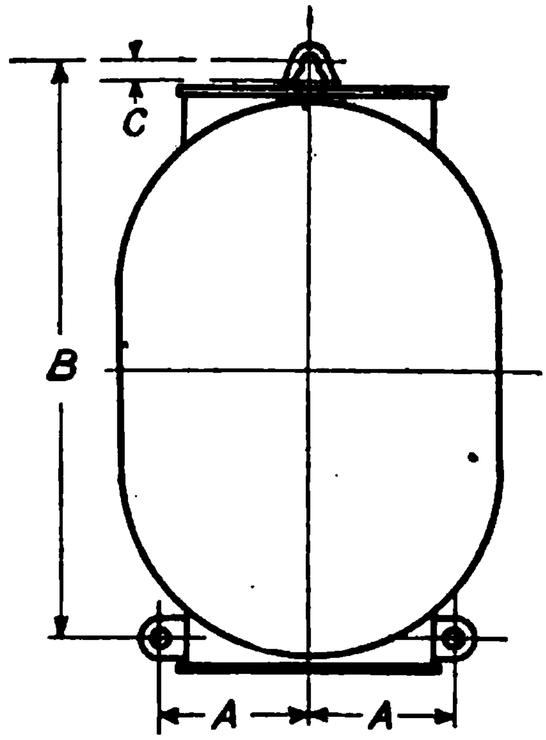


FIG. 564.—Dimensions of Westinghouse, Polyphase Watt-hour Meter.

Approximate Dimensions in Inches.

Type	Capacity Amperes	A	B	C	Total Height
Round............	5–80	2 1/2 in.	10 19/32 in.	13/32 in.	7 5/16 in. and 8 1/16 in.
A.................	5–80	2 1/2 in.	10 19/32 in.	13/32 in.	7 5/16 in. and 8 1/16 in.

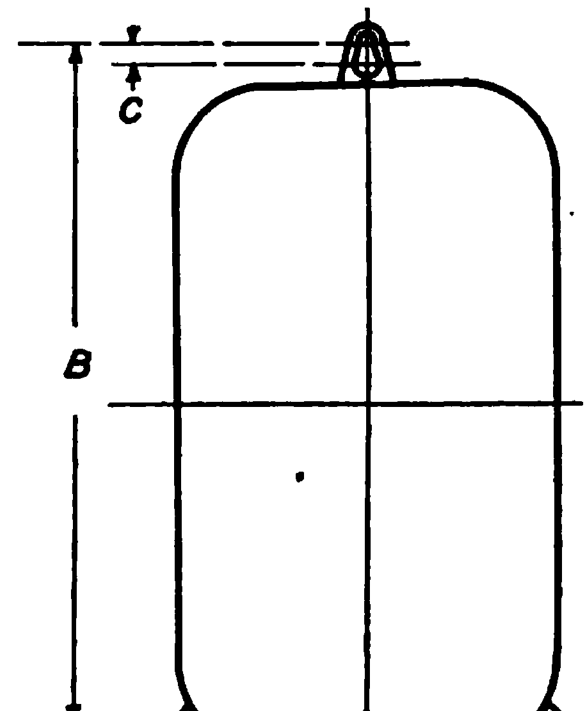


FIG. 565.—Dimension of Westinghouse, Polyphase (Heavy Current) Watt-hour Meter.

Approximate Dimensions in Inches.

Type	Amperes Capacity	A	B	C	Total Height
C, Sub A to C.......	100–300	2 15/16 in.	12 in.	7/16 in.	6 1/2 in.

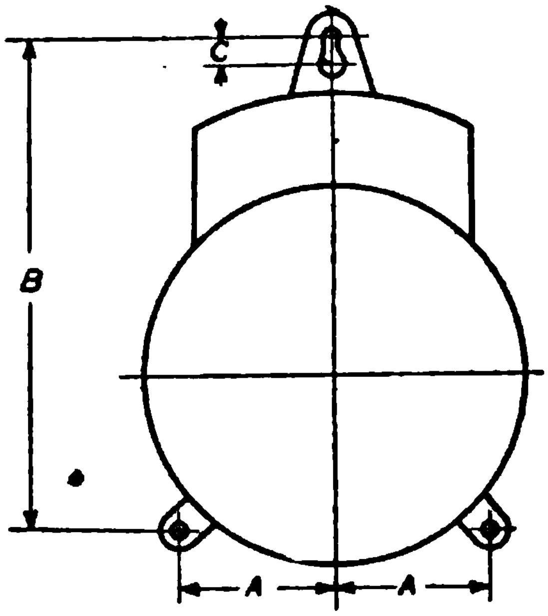


FIG. 566.—Dimensions of Westinghouse, Single-phase Watt-hour Meters.

Approximate Dimensions in Inches.

Type	Capacity Amperes	A	B	C	Total Height
B, 2-wire...........	5–80	2 13/16 in.	8 13/16 in.	7/16 in.	6 1/4 in.
B, 3-wire...........	5–40	"	"	"	"
*C, 2-wire..........	5–80	2 9/16 in.	6 9/16 in.	7/16 in.	6 in.
*C, 3-wire..........	5–40	"	"	"	"
**C, 2- and 3-wire...	5–20	2 9/16 in.	8 3/16 in.	"	6 1/16 in
**C, 2-wire.........	30–80	"	8 1/4 in.	"	"
**C, 3-wire.........	30–40	"	"	"	"
**C, 2-wire.........	100–300	"	7 1/2 in.	"	6 1/4 in.
**C, 3-wire.........	60–150	3 1/16 in.	8 7/16 in.	"	6 1/2 in.
OA, 2- and 3-wire...	5–10	2 9/16 in.	7 11/16 in.	"	5 15/16 in.

* Type C, plain and Sub A.
** Type C, Sub B to F.

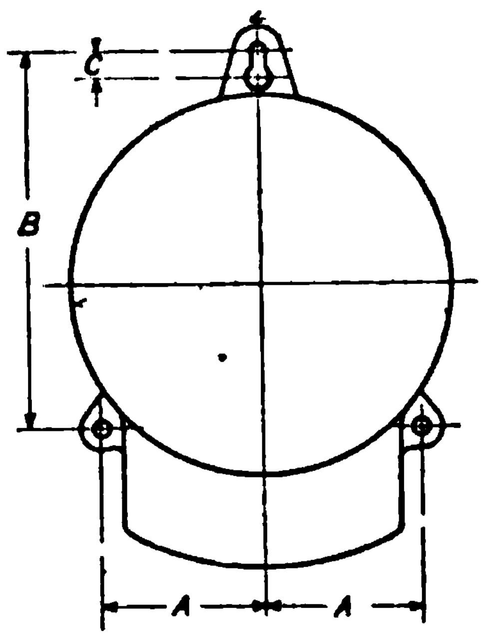


FIG. 567.—Dimensions of Westinghouse, Single-phase Watt-hour Meters. Bottom Terminals.

Approximate Dimensions in Inches.

Type	Capacity Amperes	A	B	C	Total Height
OA	5–10	2 9/16 in.	6 5/16 in.	7/16 in.	6 in.

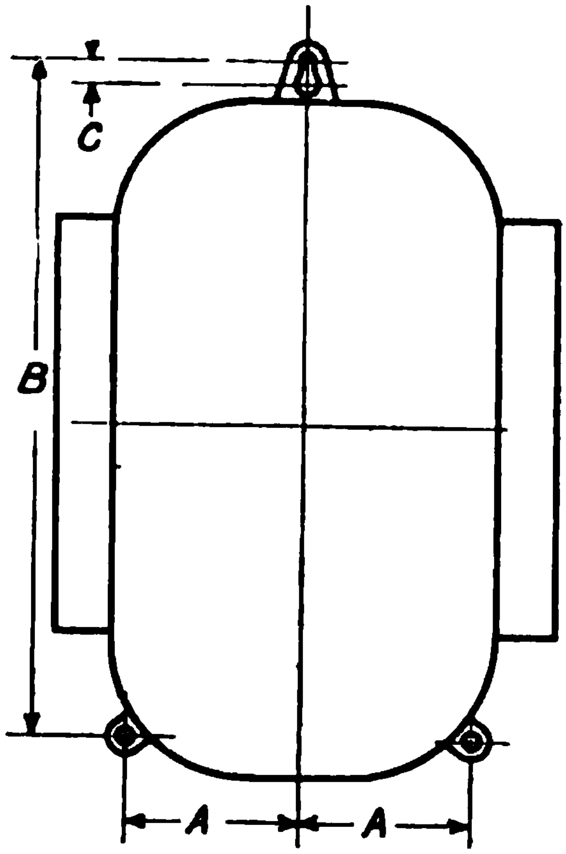


FIG. 568.—Dimensions of Westinghouse, Polyphase Watt-hour Meter.

Approximate Dimensions in Inches.

Type	Capacity Amperes	A	B	C	Total Height
C, Plain............	5–80	2 9/16 in.	10 7/16 in.	7/16 in.	6 1/8 in.
C, Sub A and B.....	5–40	2 15/16 in.	10 3/4 in.	7/16 in.	6 1/16 in.
C, Sub A and B.....	80	2 15/16 in.	10 3/4 in.	7/16 in.	6 1/2 in.

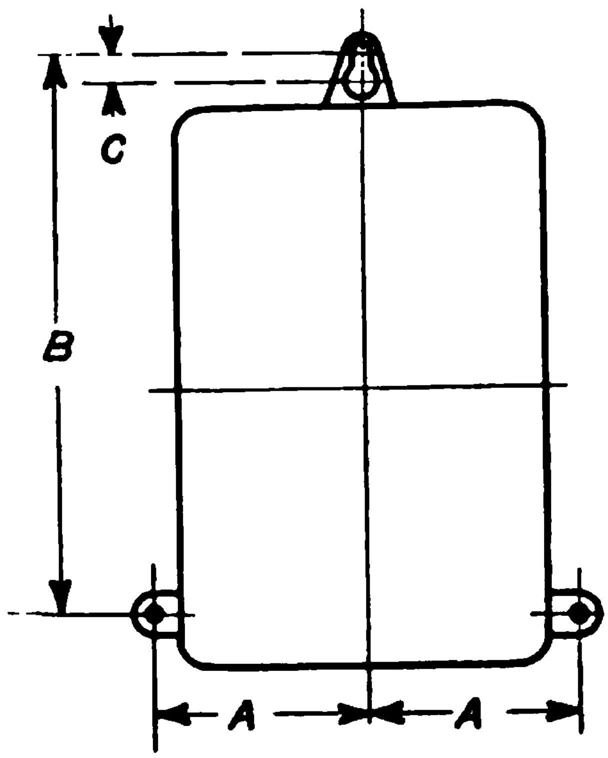


FIG. 569.—Dimensions of Westinghouse, type DC Watt-hour Meter.

Approximate Dimensions in Inches.

Type	Capacity Amperes	A	B	C	Total Height
DC, Sub A, 2-wire...	100–450	4 1/16 in.	10 1/8 in.	7/16 in.	7 7/16 in.
DC, Plain, 2-wire...	5–100	4 1/16 in.	10 in.	7/16 in.	7 3/8 in.
DC, Plain, 3-wire...	5–100	4 1/16 in.	10 in.	7/16 in.	7 3/8 in.

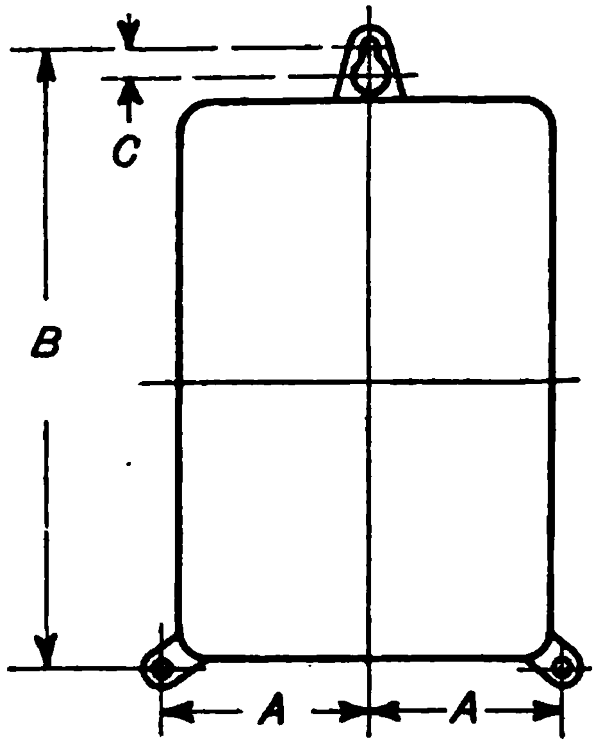


FIG. 570.—Dimensions of Westinghouse, DC Type Watt-hour Meters.

Approximate Dimensions in Inches.

Type	Capacity Amperes	A	B	C	Total Height
DC, Sub A, 2- & 3-wire	5–75	3 11/16 in.	11 5/8 in.	7/16 in.	7 1/2 in.
DC, Sub A, 3-wire...	100–300	3 11/16 in.	11 5/8 in.	7/16 in.	8 in.
CW-6, 2- and 3-wire.	5–50	3 1/2 in.	11 5/16 in.	7/16 in.	6 3/4 in.

FORT WAYNE ALTERNATING CURRENT WATT-HOUR METERS

The Fort Wayne alternating current watt-hour meter is of the induction type and is designed to register the energy of alternating current circuits, regardless of the power-factor of the circuit. It embodies the usual combination of principles of operation of the three fundamental elements, viz.: the induction motor, the eddy current generator and the registering, or revolution counting, mechanism.

The **electrical arrangement** of these meters consists of a current circuit, composed of two coils connected in series with each other and in series with the line to be measured, and a potential circuit consisting of a reactance or impedance coil and a potential coil connected in series with each other and connected across the line to be measured. In addition to this, the potential circuit contains a light load coil wound over a laminated, sheet steel member, adjustably arranged in the core of the potential coil and connected across a small number of turns of the reactance or impedance coil so as to give a field substantially in phase with the impressed e. m. f. The light load winding is further provided with a series adjustable resistance furnished for the purpose of regulating the current flowing in the light load winding, thereby providing a means of lagging the meter on high frequencies, such as 125-140 cycle circuits. The potential circuit also comprises a lag coil wound over the upper limb of the core of the potential circuit and provided with an adjustable resistance for obtaining a field component in quadrature with the shunt field.

The **arrangement of the parts and connections** of the various coils of the Type K induction watt-hour meter are shown diagrammatically in Fig. 571. The function of the various parts and windings will be described, and the parts are lettered for reference.

C is a closed circuit aluminum cup or armature, arranged so as to be cut by the fields of the current and potential circuit coils.

SFC and SFC' are the main series field coils wound in opposite directions.

SF is the shunt or potential circuit field coil to produce a field that is proportional to the impressed e. m. f.

SFI is a portion of the potential circuit iron used to complete the magnetic circuit for the potential circuit coil.

60 cycle PC is a closed circuit secondary winding or phasing coil for lagging the meter for circuits of standard frequency.

60 cycle PCA is an adjustable resistance provided to regulate the current in the 60 cycle phasing coil.

140 cycle PC and FC is the coil arranged to produce a starting torque for friction compensation, which is also used as a phasing coil to lag the meter for high frequency circuits.

LLA, shown in Fig. 572, is the light load adjusting arm.

140 cycle PCA is an adjustable resistance placed in series with the friction compensation coil, both being connected in series and across a few turns of the impedance coil IC.

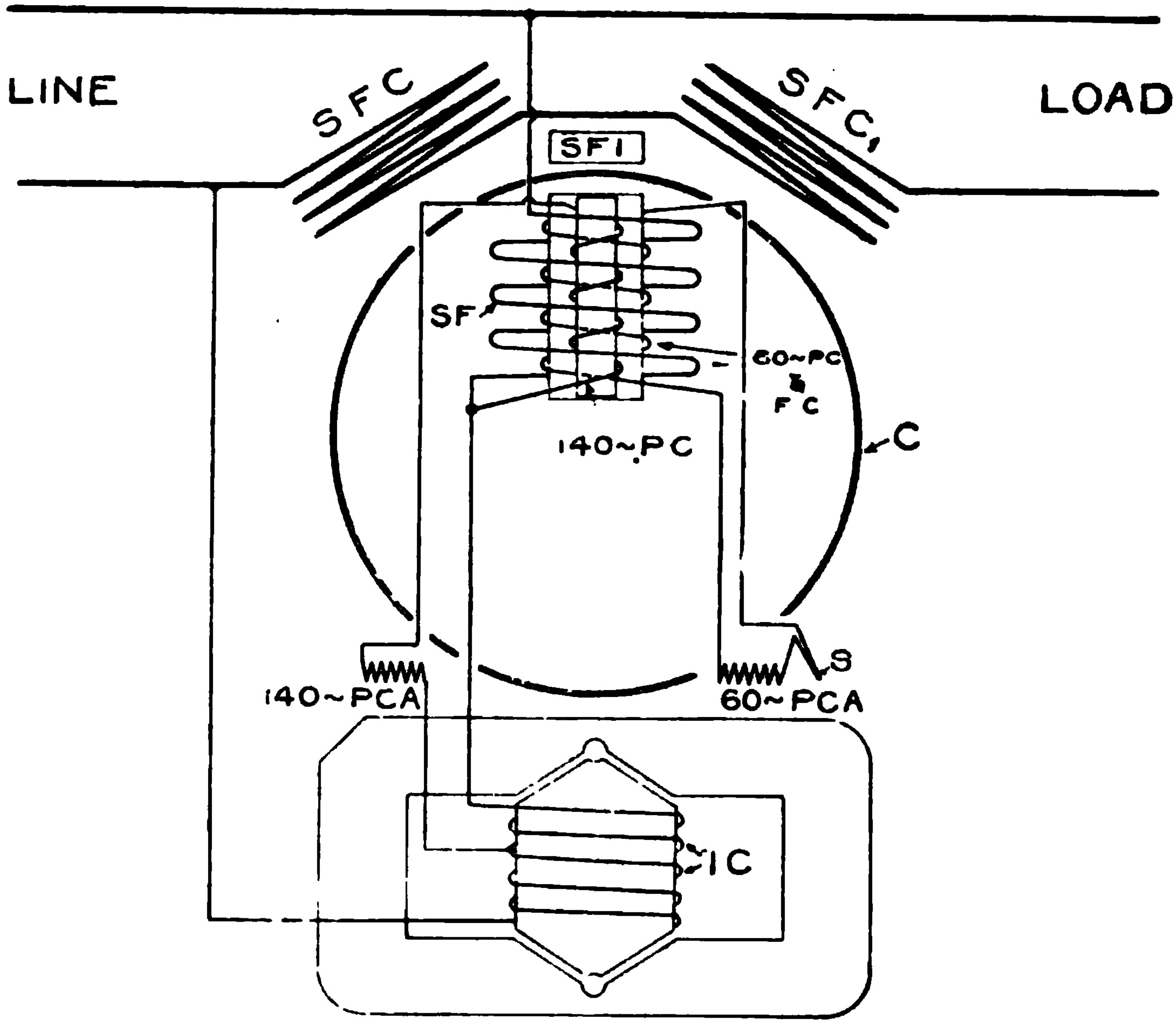


FIG. 571.—Fort Wayne, Type K, Induction Watt-hour Meter.

IC is the reactance or impedance coil, and is connected in series with the potential circuit field coil.

S is a switch in series with the 60 cycle phasing coil and the adjustable resistance, and provides a means for adapting the meter for a high or low frequency circuit. When the switch is open the meter is properly compensated or lagged for a 140 cycle current, and when closed the meter is compensated for a 60 cycle current.

The **phase relations of the magnetic fields** produced by the various coils in the Type K meters are represented diagrammatically in Figs. 573, 574 and 575.

In the vector diagrams, the line OX represents the position of the e. m. f. on the potential circuit, and the line OY represents the proper

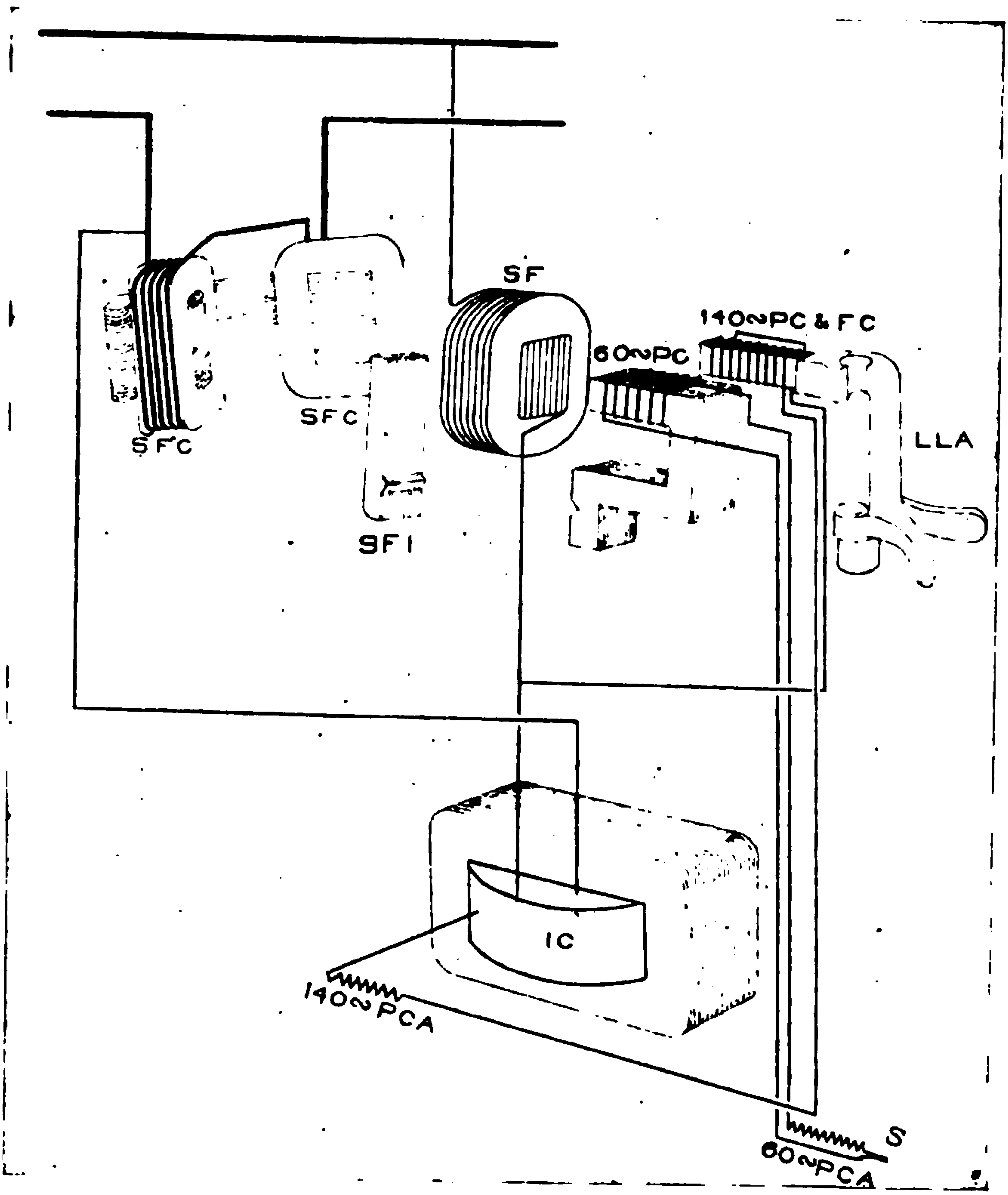


FIG. 572.—Relation of Parts in Fort Wayne, Type K_3, Induction Watt-hour Meter.

phase position for the field of the potential circuit, which is 90 degre from OX.

As the Type K meter is designed to operate on either a 140 or a

cycle circuit, it is necessary that it should be double lagged, that is, the phase relation of the fields should be properly compensated for each

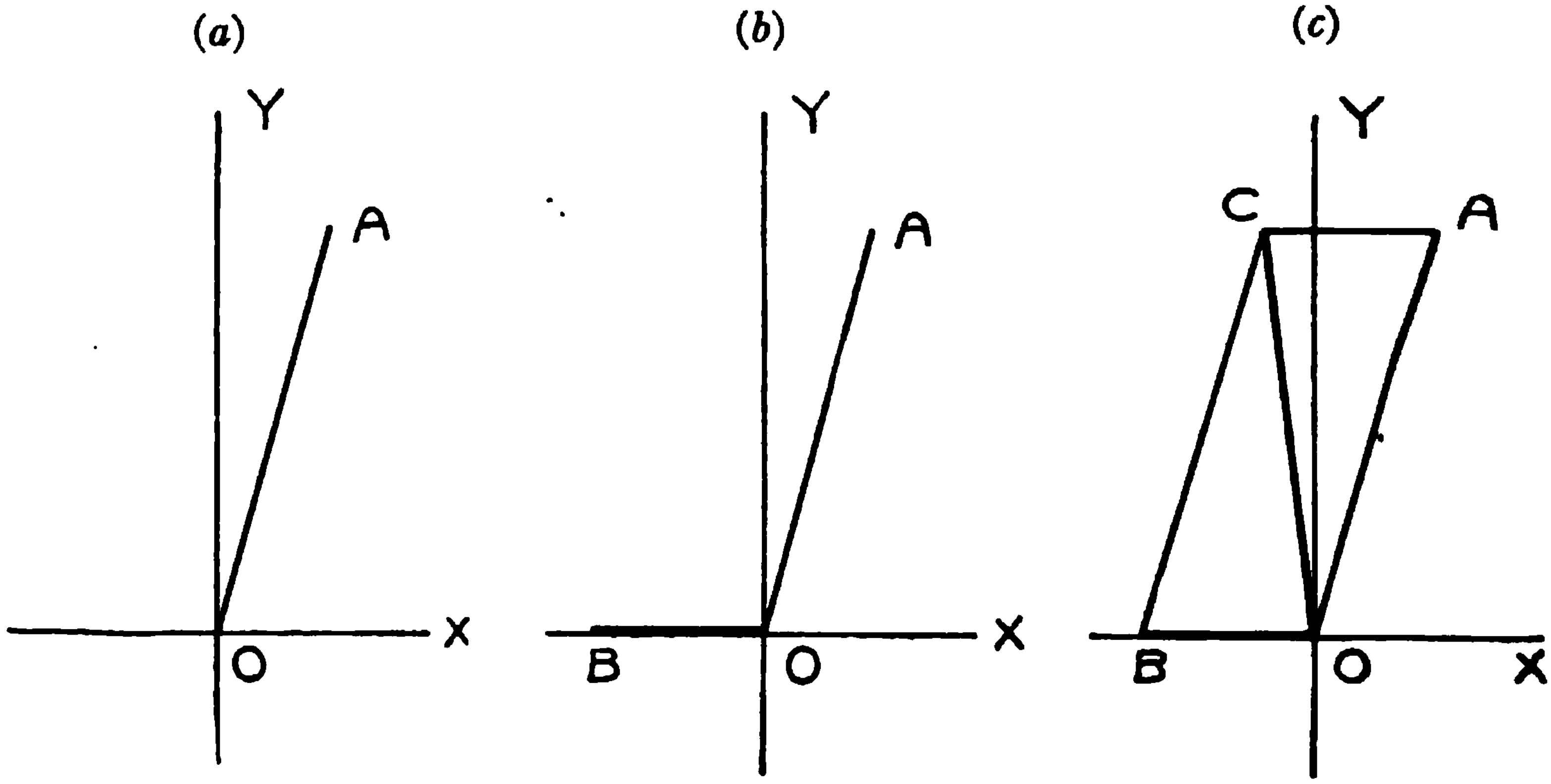


FIG. 573.—Fundamental Vectors of Potential Circuit of Type K, Induction Watt-hour Meter.

frequency. The lagging of the meter for a 140 cycle circuit will be considered first.

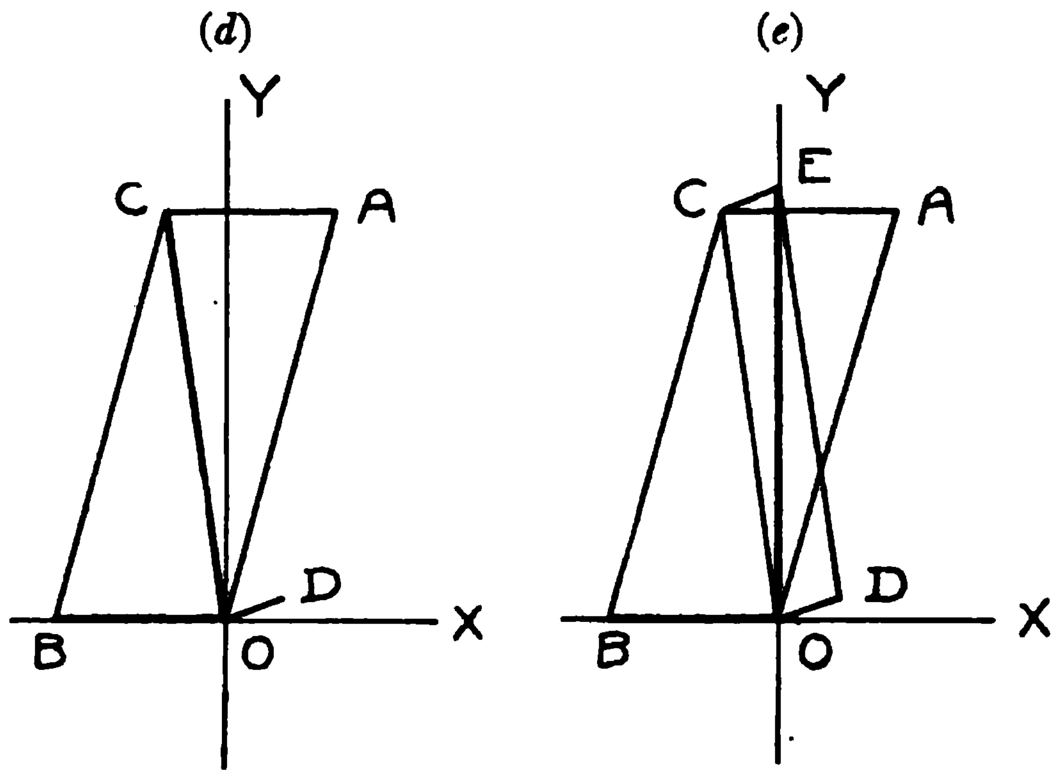


FIG. 574.—Vectors for 140-Cycle Compensation of Type K, Induction Watt-hour Meter.

OA (Fig. 573 a) represents the phase position and magnitude of the field established by the potential circuit field coil; the large displacement of the field with respect to OX resulting from the large

reactance component, is obtained by the impedance coil and potential circuit field coil.

OB (Fig. 573 b) represents the phase position and magnitude of the field due to the currents induced in the closed circuit armature by the fields of the potential coil.

OC (Fig. 573 c) represents the direction and magnitude of an equivalent or resultant field produced by the fields OA and OB. The phase position of OC is beyond 90 degrees.

OD (Fig. 574 d) represents the component field produced by the 140 cycle phasing coil or friction compensator, the magnitude of this

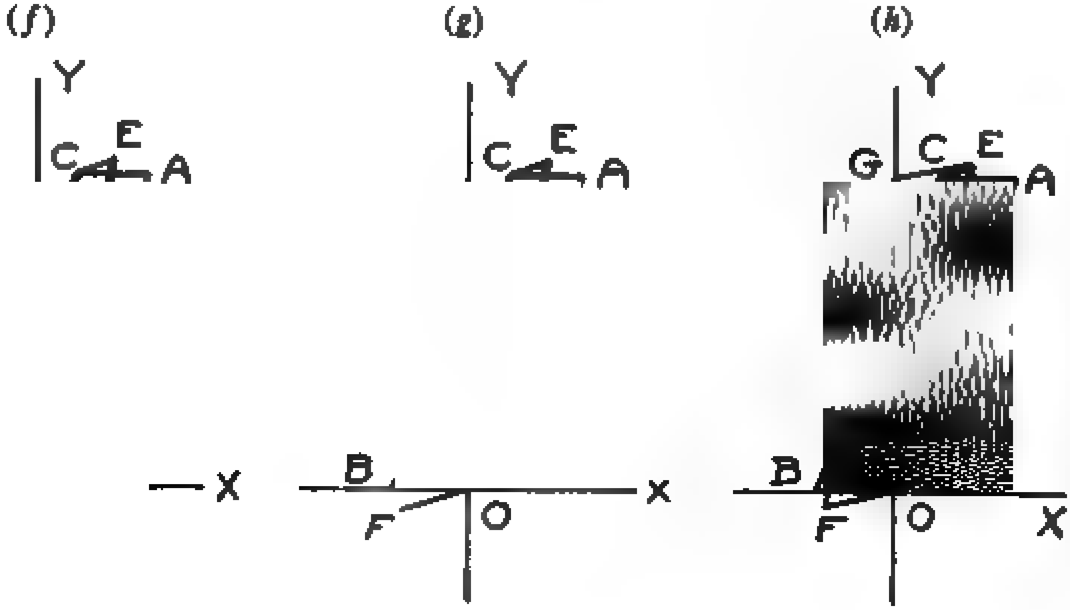


FIG. 575.—Vectors for 60-Cycle Compensation of Type K, Induction Watt-hour Meter.

component being controlled by a resistance in series. The resistance may be varied to increase or decrease the amount of current in the phasing coil, thus controlling the magnitude of the field produced.

OE (Fig. 574 e) represents the resultant field produced by the combined action of the components OC and OD. The magnitude of the component OD is adjusted so that OE will assume a 90 degree position. Therefore, the meter will accurately register the true energy of the circuit.

When a meter lagged, as described, for a 140 cycle circuit is connected to a 60 cycle circuit, the 90 degree relation of the magnetic fields no longer exists, and the resultant flux represented by OE has a phase position less than 90 degrees, as shown in Fig. 575 f. This is due to the reduction in the rate of alternations of the circuit and consequent decrease in the reactance, which lessens the magnitude of the components

OB and OD and the angles XOA and XOD, and therefore alters the phase relations.

In order to again establish the 90 degree phase relation, the 60 cycle phasing coil switch S is closed, which introduces another component field.

OF (Fig. 575 g) represents the phase position and magnitude of the field produced by the 60 cycle phasing coil.

OG (Fig. 575 h) represents the resultant field produced by the combination of the component OF and resultant component OE. This

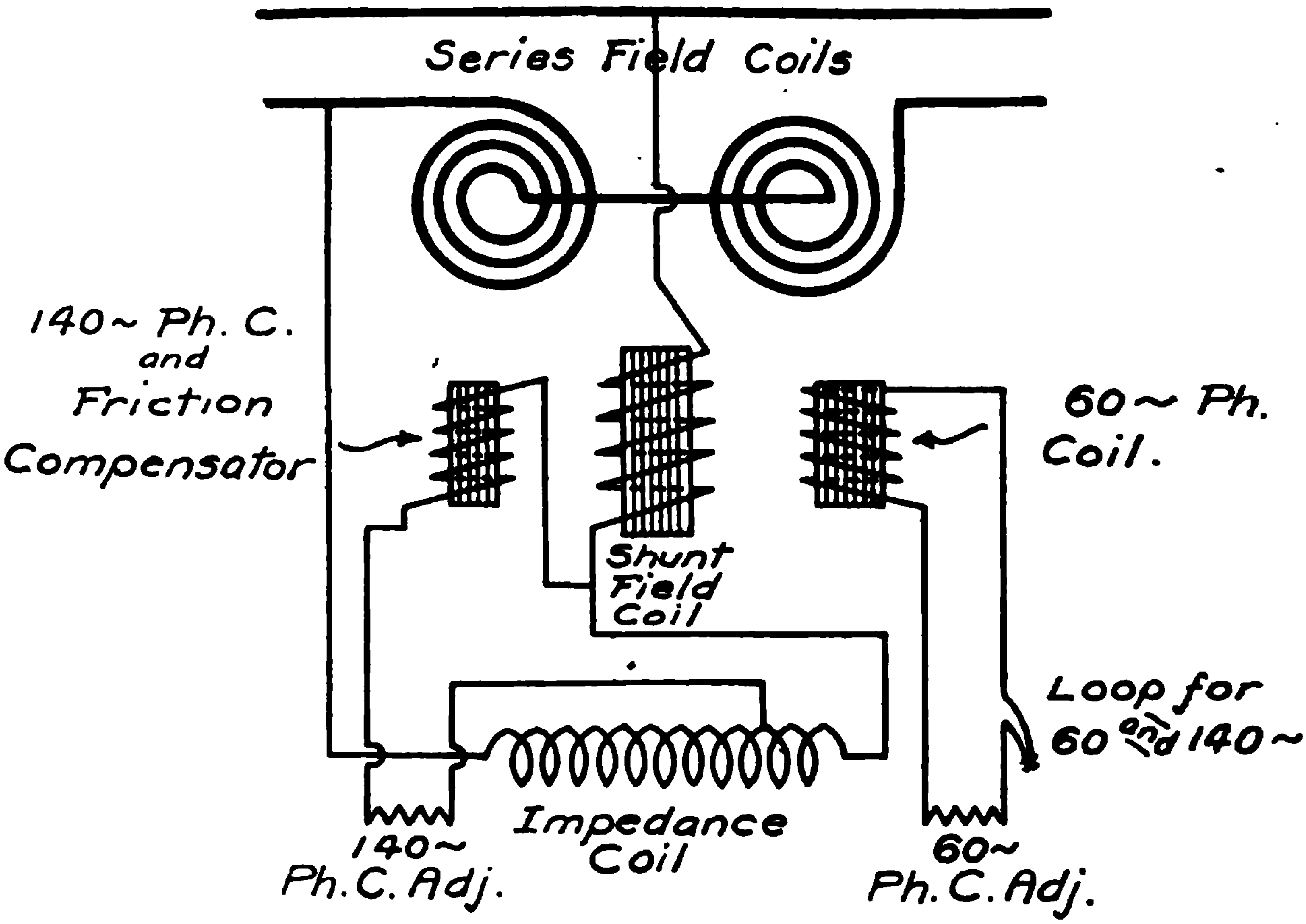


FIG. 576.—Internal Connections of Type K, Induction Watt-hour Meter.

field, OG, lies on the line OY and has a phase displacement of 90 degrees with respect to OX.

The meter is then properly lagged for a 60 cycle current and will accurately register the energy in the circuit.

One of the phasing coils is wound on an adjustable arm and placed centrally in the potential circuit field coil, producing the desired additional field to give a resultant potential field having a 90 degree relation with respect to the impressed e. m. f., as explained. The field established by this coil is not in phase with that of the potential coil, and when in position in the potential coil has a demagnetizing effect on account of the direction of its winding and consequent phase position of its field.

When moved from the central position, the field established, cuts the rotor at a slight angle and produces an unsymmetrical condition and slight rotating-field effect. A torque is thus produced that is sufficient to compensate for the friction without disturbing the phase displacement of the potential circuit field as a whole.

Fig. 572 shows the component parts of a Type K2 meter, the arrangement of the parts and manner in which they are assembled and connected is also shown.

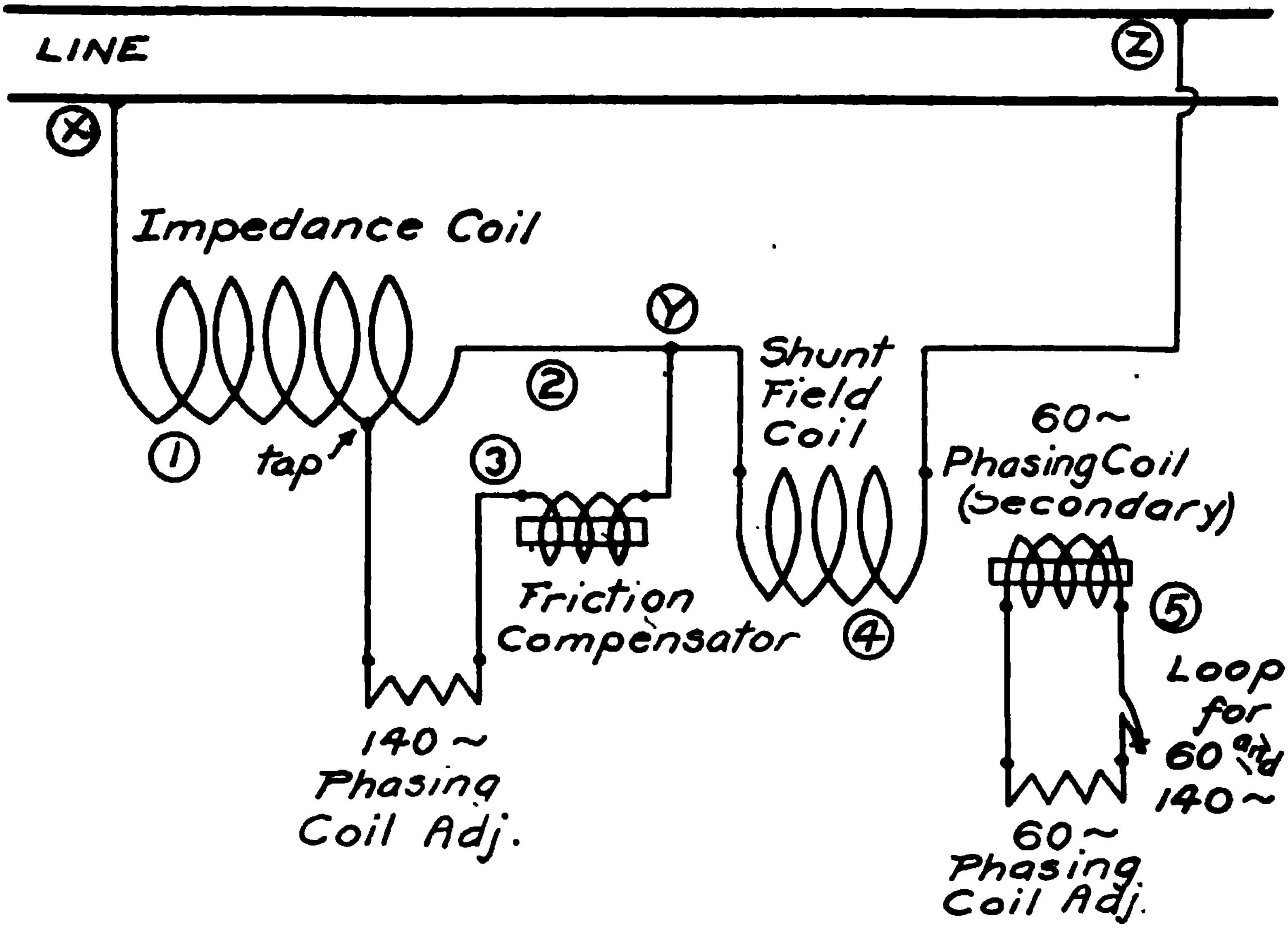


FIG. 577.—Connections of Potential Circuit in Type K, Induction Watt-hour Meters.

Fig. 576 shows diagrammatically the connections and coils arranged in their relative positions.

Fig. 577 shows diagrammatically the connections of the potential circuit and its auxiliary coils.

Description of Various Types

Type K

The Type K meter (Fig. 578) is rectangular in shape and consists of a cast iron base into which are mounted the various elements

The reactance or impedance coil is provided with a core of sheet steel punchings and arranged to slip into a pocket in the lower part of the base, this pocket having a back cover secured from the inside to prevent tampering. The core is so arranged that by removing two screws, the core and coil may be readily removed for repairs.

The current coils are wound over cast brass spiders suitably secured to the milled surfaces in the base. It is obvious, therefore, that the magnetic circuit of the current coils is made up largely of air, there being no laminated core in the coils.

These meters are provided both with a four or five-dial register and with dull porcelain dial faces and further provided with a removable bracket carrying the ratio gears, so as to readily change the capacity of the meter register.

FIG. 578.—Fort Wayne, Type K, Form SAA, Induction Watt-hour Meter.

These meters are provided with either one or two magnets arranged to move in a vertical plane in a manner to embrace more or less of an effective cup area, thereby providing ready means of altering the speed at full load and giving a full load adjustment. Raising the magnets decreases the speed, and lowering the magnets increases the speed.

The **light load adjustment** is effected by moving the screws A and B, Fig. 579. The speed of the meter can be increased on light loads by loosening screw A and tightening screw B and decreased by loosening screw B and tightening screw A. The clamping screw C must not be loosened in making this adjustment.

Type K wattmeters used on 125 to 140 cycle circuits can be changed for use on 60 cycle circuits without taking the meter out of service. To change from high frequency (125 to 140 cycles) to low frequency (60 cycles) close the circuit at D, Fig. 579, by soldering the large copper wires together. To change the meter from low frequency to high frequency, open the circuit at D by unsoldering and separating the ends of the copper wires.

After making this change the speed of the meter should be taken. If not correct the position of the permanent magnet should be adjusted until the correct speed is obtained.

To facilitate repairs, all parts are standard and interchangeable. If

Fig. 579.—Internal Front and Side View of Fort Wayne, Type K, Form SAA, Induction Watt-hour Meter

the meter should become damaged or much worn it should be taken out of service, repaired and recalibrated. In preparing a meter for calibration all parts should be carefully examined and cleaned. If the meter has been operating with a broken jewel, the shaft should be renewed as well as the jewel. The shaft may be renewed by removing register bracket complete with register, and taking the cup and shaft out bodily (Fig. 580).

When **renewing the jewel** bearing, screw the jewel in until the head jams firmly against the head of the jewel sleeve. Only the very best clock oil should be used in oiling the different bearings. The worm must never be oiled.

The cover consists of an aluminum casting fitting into a groove in the

base, this groove being lined with heavy felt to render the meter dust and tamper proof. The cover is provided with one opening at the top

FIG. 580.—Moving Element.

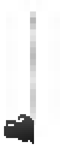


FIG. 581.—External View of Fort Wayne, Type K, Form SAB, Induction Watt-hour Meter, with Glass Cover

through which the register can be viewed and through which the rotation of the cup can be seen. The cover is secured by a single sealing screw

FIG. 582.—Fort Wayne, Type K, Form SAB, Induction Watt-hour Meter, with Separate Sealed Terminals.

at the top, the arrangement being such that a prong cast in the lower surface of the cover engages a cast eyelet in the base much after the fashion of a hinge. The screw is provided with a sealing wire to pre-

vent tampering. The nameplate is cast directly into the cover and contains various data, such as the ampere, voltage and frequency rating, together with the serial number and form.

The three-terminal construction is provided in these meters—one at either side, near the top, into which one line and one load wire enters, and a small terminal at the middle of the top for the shunt tap. In the case of three-wire meters, however, both sides of the line are carried

FIG. 583—Internal View of Fort Wayne, Type K, Form SBA, High Torque, Induction Watt-hour Meter.

through the meter and the potential circuit is connected across the two outside lines (Figs. 581 and 582).

All Type K single-phase meters having one magnet are low torque meters, and the two magnet meters of this type (also Types K_1 and K_2) are high torque meters (Figs. 583 and 584).

The direction of rotation in these meters is clockwise, when vie

from above, and the calibrating constants are given in Chapter XV. The formula used for calibrating these meters is:

$$\frac{\text{Rev} \times 100 \times \text{K}}{\text{Seconds}} = \text{Watts}$$

The low torque and high torque forms of this type were produced in 1899 and 1902, respectively.

Type K_1 Meters

The general electrical design of the Type K_1 meter is exactly the same as the Type K meter, with some modifications in the windings and magnetic circuits to reduce the losses.

The general mechanical details of the Type K_1 meter are exactly the same as the Type K meters, except that the rotating element is pro-

FIG. 584.—Fort Wayne, Type K, Polyphase, Induction Watt-hour Meter, Switchboard Type.

vided with a removable lower pivot, four-terminal construction throughout, watt-hour calibrating constant, and a brass nameplate. In addition to this, some changes in the general mechanical arrangement have been made, which do not affect the general appearance in any manner whatever (Figs. 585 and 586).

The removable lower pivot is so arranged that by removing the jewel screw and using a pivot wrench, the pivot may be removed and replaced without removing the rotating element.

To facilitate adjustment the magnets are provided with a micrometer adjusting screw immediately behind the lower portion of back half of magnet and immediately below the magnet bracket. Owing to the construction involved, which consists of a simple screw arranged to operate in a tapped hole in the magnet bracket, and the head of the screw being enlarged so as to fit a milled recess in the black portion of the magnet, turning the screw to the right raises and turning to the left lowers the magnet. To accomplish this, to the best advantage, the magnet

Fig. 585.—External View Fort Wayne, Type K_1, Form SAB, Induction Watt-hour Meter

Fig. 586.—Fort Wayne, Type K_1, Form MAB, Polyphase, Induction Watt-hour Meter

clamp retaining screws should just be loosened sufficiently to allow the satisfactory movement of the magnet.

The terminals are located at the top of the meter, and in both two and three-wire meters, both sides of the line are carried through the meter, the line wires entering at the left and the load wires leaving at the right.

The cover which is of the same general construction as that employed in the Type K meter is provided with two openings, one for viewing the register and one for observing the revolution of the cup (Fig. 585).

Both the low and high torque forms of this type were produced in 1908.

Type K_2 Meters

The general electrical design of tl
as the Type K_1 meters, except that

FIG. 587.—Internal View of Fort Wayne, Type K_2 and K_3, Form SAA, Low Torque, Induction Watt-hour Meter, showing Light Load Adjustment. (See instructions for Fig. 579.)

FIG. 588.—Internal View of Fort Wayne, Type K_2 and K_3, Form SBB, High Torque, Induction Watt-hour Meter, showing Light Load Adjustment. (See instructions for Fig. 579.)

circuit have been greatly reduced and a sheet steel core and shield provided. This has the effect of greatly reducing the losses in the current circuit and shielding the measuring system from external fields (Figs. 587 and 588).

The general mechanical details of the Type K_2 meter are exactly the same as the Type K_1 meter.

Both the low and high torque forms of this type were produced in 1909.

Type K_3 Meters

The general electrical design of the Type K_3 meter is exactly the same as the K_1 and K_2 meters, except that the weight of the rotating element has been considerably reduced and the windings and magnetic circuits modified slightly to reduce the losses.

The general mechanical details of the K_3 meter are exactly the same as the K_2 meter in every respect (Figs. 589, 590, 591 and 592).

Fig. 589.—External View of Fort Wayne, Type K_1, K_2 and K_3, Form SAA, Induction Watt-hour Meter.

Fig. 590.—External View of Fort Wayne, Type K_1, K_2 and K_3, Form SBE, Induction Watt-hour Meter

The low torque and high torque forms of this type were produced in 1909 and 1910, respectively.

Type K_4 Meters

The general electrical design of the Type K_4 meter is considerably different from any of the former models. The arrangement consists of a current circuit of one coil wound over a sheet steel core, and a potential circuit of a single coil arranged to slip over an E-shaped core, so located with reference to the current coil core, and another core known as the magnetic shield, as to provide motor mechanism of compact design.

The damping system consists of a semi-circular shaped drag magnet so constructed and formed as to present two pole faces projecting to the

FIG 591.—External View of Fort Wayne, Type K_3, Form SBC, Induction Watt-hour Meter

center and in a circle concentric with the cup. By placing a steel punching bent to the proper radius on the inside of the cup, an astatic damping system is provided (Fig. 593).

Lagging is accomplished by means of a punched copper plate arranged

FIG. 592 —Fort Wayne, Type K_3, Polyphase, Induction Watt-hour Meter. A and B indicate light load adjustment.

to embrace the middle pole of the potential core. The lag is fixed at the factory and is not arranged for adjustment.

A, Full Load Micrometer Adjustment; B, Set Screw for Locking Full Load Adjustment; C, Light Load Adjustment.

FIG. 593.—Fort Wayne, Type K_2, Form SAA, Induction Watt-hour Meter.

The light load adjustment mechanism consists of a sheet copper punching embracing the middle pole of the potential core, pivoted at th

top, and actuated by an eccentric cam at the bottom in such a manner that the plate may be shifted from one side to the other, thereby providing a means of light load adjustment.

The base of this meter consists of a drawn steel base provided with three-point support, with a suitable terminal chamber at the bottom. The two lower supporting screws are accessible only through the terminal chamber, making it impossible for unauthorized parties to change the position of the meter after the terminal chamber cover has been sealed in position.

The terminals, which are arranged for carrying both sides of the line through the meter, are moulded in an insulating compound and arranged to be assembled as a unit in the terminal chamber. The

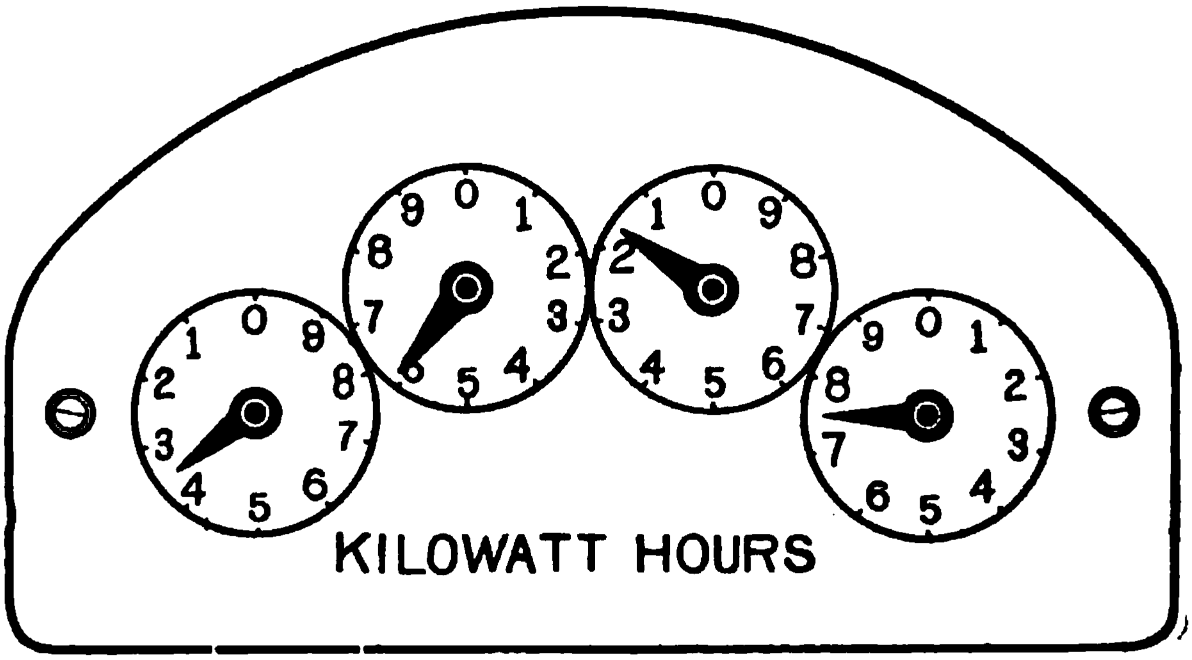


FIG. 594.—Dial face of Fort Wayne, Type K_4, Watt-hour Meters.

line wires enter at the left and the wires to the load leave at the right side of the meter.

The register, which is of the four-dial type, embodies a double worm reduction. The dial face is of dull porcelain (Fig. 594).

The rotating element, which is of the same general design as that used in the former meters, is considerably lighter in weight. The shaft is provided with a removable lower pivot. The various elements, such as the measuring system, the damping system and registering system, are secured to a cast aluminum alloy frame, secured to supporting posts by three-point support to the base.

The cover, which is a one-piece metal stamping, is secured to the base by a three-point bayonet lock, a simple movement locking the cover in position. A sealing screw is provided to prevent tampering. The joint between the base and cover is dust-proofed by a heavy piece of felt

in the bottom of the groove. The cover is provided with a large circular opening through which the interior of the meter may be viewed.

In Types K_1, K_2, K_3 and K_4 watt-hour meters the direction of rotation of the moving element is clockwise, when viewed from above, and the calibrating constant which is given in terms of the watt-hour constant is stamped on the cup. The register ratios will also be found stamped on the back plate of the register.

The formula used for calibrating these meters is

$$\frac{3{,}600 \times K_t \times \text{Rev.}}{\text{Seconds}} = \text{Watts.}$$

The **test constants** and **gear ratios** for different capacities will be found in Chapter XV.

When **installing the standard front connected meter,** it should be secured by a screw through the top plug to a solid perpendicular support. It should then be carefully leveled before screws are set in the lower lugs. To level a standard form meter, remove the packing wedge and lower the jewel post nut so that the rotating parts will rest on the jewel. Place a light non-magnetic weight on the edge of the aluminum cup and adjust the position of the meter until the weight remains in any position given it. To level the separate seal meter, use the milled boss on top of the meter: with a small spirit level, the meter should then be leveled carefully both ways. The meter should then be connected in circuit, care being taken to secure a good, firm contact with the circuit wires. Remove the packing wedge and lower the jewel post nut so that the rotating parts will rest on the jewel. When the meter is properly connected in circuit the cup will rotate to the left or in a clockwise direction when viewed from the top.

Type K single-phase watt-hour meters are of three regular forms. The standard form is Form S A A. The terminals of Form S A A meters are led directly out to the line and the meter is sealed by sealing on the case.

In Form S A B meters, the external connections are sealed in a separate terminal box with a separate seal. The seal for the case is similar to that used in Form S A A meters. The terminal box is situated in the upper part of the meter and is covered from the top by a metal cover fastened with one screw which is drilled for the sealing wire.

The Form S A C meter is the switchboard pattern of the Type K meter. It is designed for mounting on the front of the switchboard: It is provided with back-of-board connections and is secured to the board from the back.

The following are additional form numbers of Type K watt-hour meters which have been tabulated with the foregoing form numbers, and for each of the forms is given data pertaining to the number of circuits, terminals, cover and magnets.

SINGLE-PHASE

Form	Circuit	Terminals	Cover	No. of Magnets
SAA	Single-phase	Sealed in meter	Metal	One
SAB	" "	Separately sealed	"	"
SAC	" "	Back connected	Round glass swb.	"
SAD	" "	Sealed in meter	Moulded glass	"
SAE	" "	Separately sealed	" "	"
SBA	" "	Sealed in meter	Metal	Two
SBB	" "	Separately sealed	"	"
SBC	" "	Back connected	Round glass swb.	"
SBD	" "	Sealed in meter	Moulded glass	"
SBE	" "	Separately sealed	" "	"
SBK	" "	Cable	Metal	"
SBL	" "	"	Moulded glass	"

POLYPHASE

Form	Circuit	Terminals	Cover	No. of Magnets
MAA	Polyphase	Sealed in meter	Metal	
MAB	"	Separately sealed	"	
MAC	"	Back connected	Round glass swb.	
MAD	"	Sealed in meter	Moulded glass	
MAE	"	Separately sealed	" "	
MAK	"	Cable	Metal	
MAL	"	"	Moulded glass	

TABLE OF DESCRIPTIVE DATA ON FORT WAYNE WATT-HOUR METERS

Type	K L.T.	K H.T.	K_1 L.T.	K_1 H.T.	K_2 L.T.	K_2 H.T.	K_3 L.T.	K_4 L.T.	K P.P.	K_1 P.P.	K_3 P.P.
Date of production	1899	1902	1908	1908	1909	1909	1909	1910	MAA-1903 MAB1904	1908	1910
Speed at rated capacity, rev. per min.	36⅔	36⅔	36⅔	36⅔	36⅔	36⅔	36⅔	36⅔	18⅓	18⅓	36⅔
Torque at rated capacity, mm-g.	40	65	40	65	40	65	45	45	45 per Element	45 per Element	45 per Element
Weight of Rotor, g.	45	45	45	45	45	45	32	21	62	62	65
Ratio of torque to weight of Rotor	0.88	1.44	0.88	1.44	0.88	1.44	1.4	2.14			
Volts drop in current coils, at rated capacity	0.337	0.675	0.337	0.675	0.125	0.194	0.194	0.118	0.337 per Element	0.337per Element	0.194per Element
Watt loss in current coils, at rated capacity	1.68	3.37	1.68	3.37	0.625	0.97	0.97	0.59	1.68 per Element	1.68 per Element	0.97 per Element
Watt loss in potential circuit	3	3	2¼	2¼	2	2	1.75	1.75	2¼ per Element	2¼ per Element	1.75 per Element
Temperature coefficient per degree C.	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.03	0.05	0.05	0.04
Power-factor of potential circuit	.20	.20	.20	.20	.18	.18	.16	.17	.20	.20	.20

Types K, K_1, K_2 and K_3 meters are made in sizes of 5 to 800 amperes inclusive, in the customary sizes for the following voltages: 100/125, 200/250, 400/499 and 500/625 in both single-phase and polyphase meters, except for the three-wire meter, which is made for currents up to 150 amperes only. Type K_4 is made in sizes of 5 to 25 amperes only.

All Type K watt-hour meters are classified according to the number of wires and voltage of the system for which they are designed. The class 2-50 meter is a two-wire, 50 volt meter, class 3-220 meter is a three-wire, 220 volt meter and class 2-2200 meter is a two-wire meter for use on a 2200 volt circuit.

The standard finish for Type K meters, Form S A A and Form S A B is a black japan finish. The standard finish for Form S A C meters is a black oxidized Bauer-Bauff finish.

With all Type K watt-hour meters on voltages higher than 220 volts, a small voltage transformer is used in the potential or voltage circuit.

With all meters larger than 250 amperes capacity, a current transformer is used in the series or current circuit.

These meters may be used on circuits of higher voltages than those listed in the tables of standard ratings by using a voltage transformer in the potential circuit and a current transformer in the series circuit in all capacities, thus keeping the high line potential from the interior of the meter.

The following diagrams show the external connections of Fort Wayne watt-hour meters for frequencies of over 35 cycles. For frequencies from 25 to 35 cycles an external reactance must be connected in the potential circuit on account of the decreased impedance due to the lower frequency. With meters which are used with instrument transformers, the external reactance is connected in the low-tension side of the voltage transformer, and in the potential circuit (Figs. 595 to 620).

External dimensions of these types of watt-hour meters are given in Figs. 621 to 628.

EXTERNAL CONNECTION DIAGRAMS

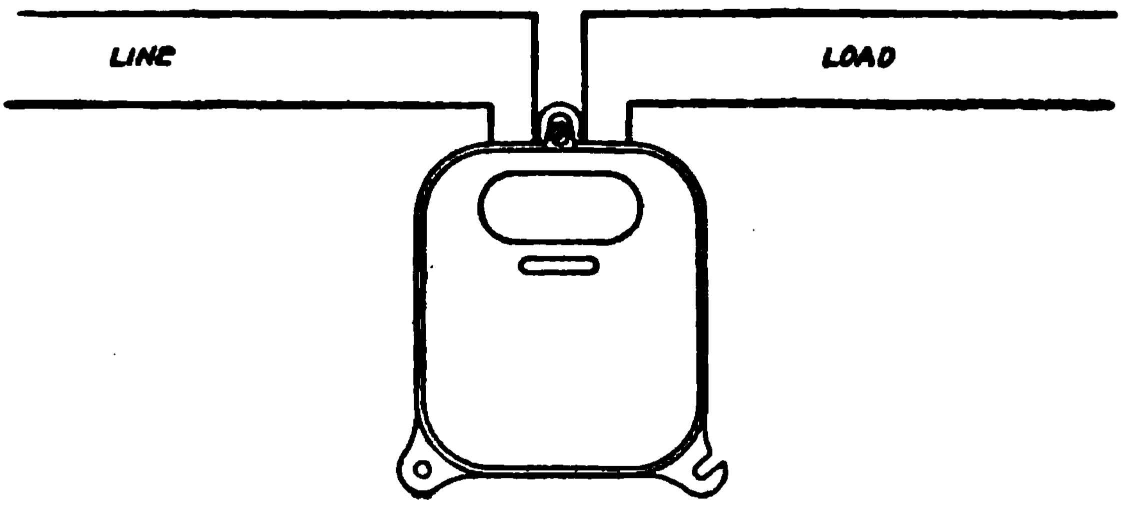


FIG. 595.—External Connections for Types K_1, K_2, K_3, Single-phase, 2-wire, Induction Watt-hour Meters, 5–50 Ampeies, 100–625 Volts.

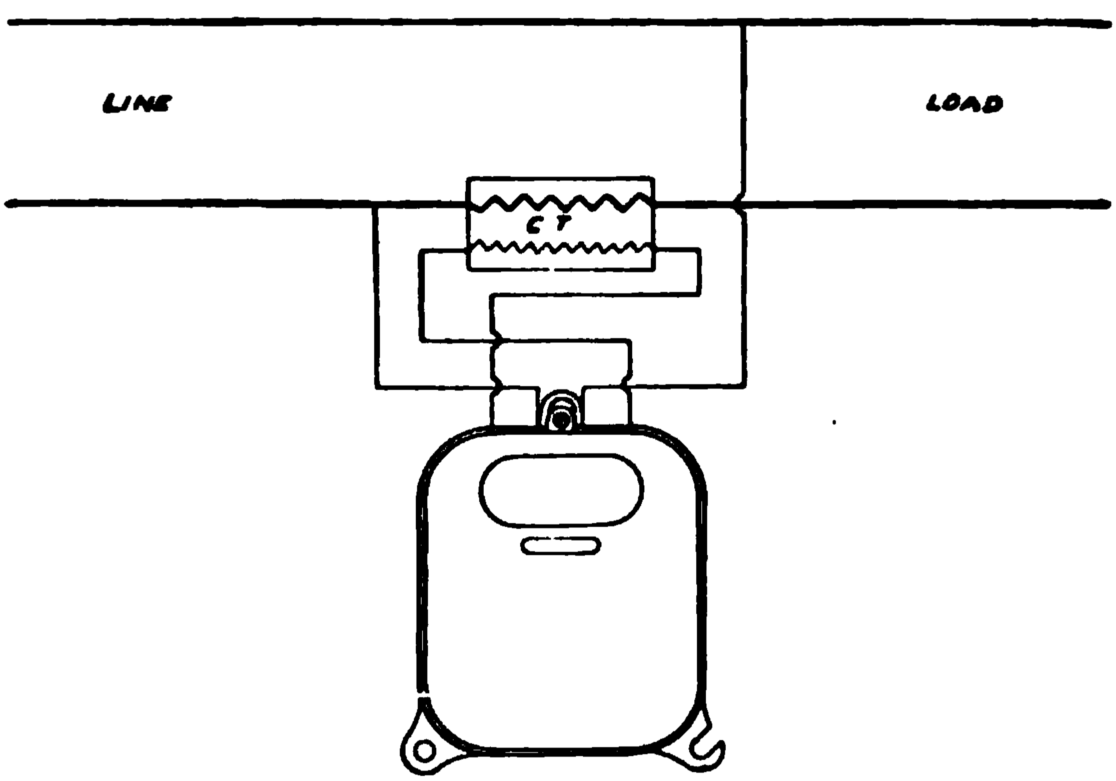


FIG. 596.—External Connections foi Types K_1, K_2, K_3, Single-phase, 2-wire, Induction Watt-hour Meters, above 300 Amperes, 100–625 Volts.

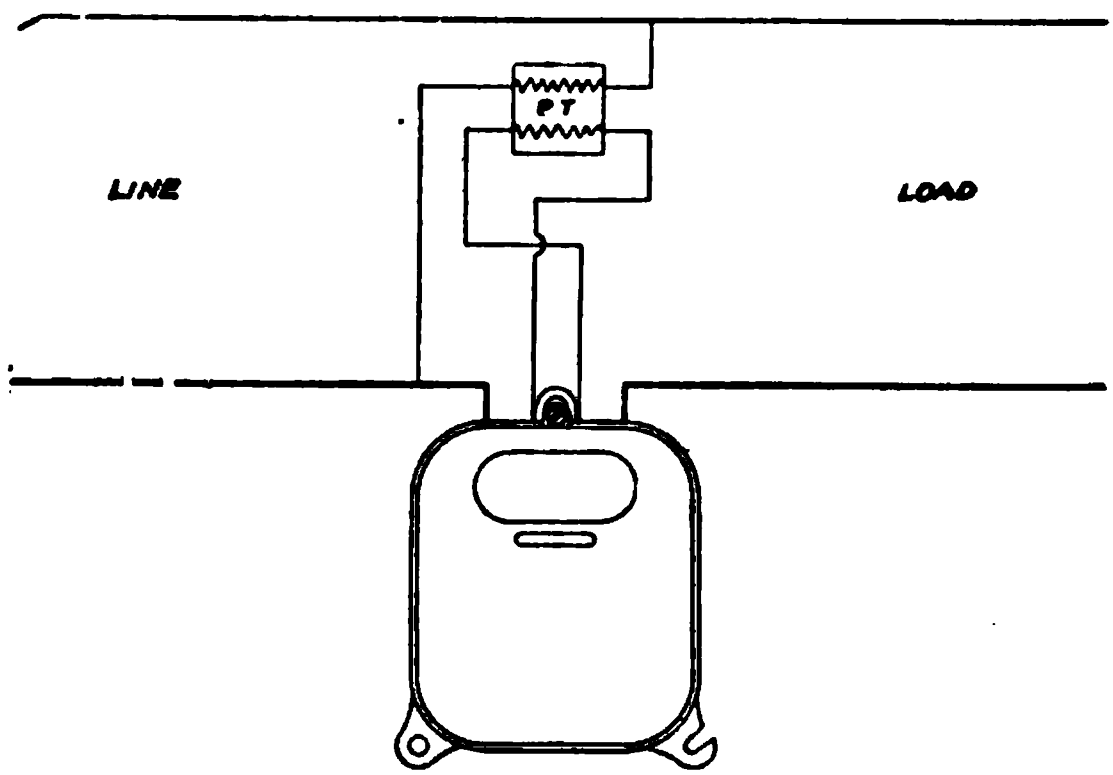


FIG. 597.—External Connections for Types K_1, K_2, K_3, Single-phase, 2 wire, Induction Watt-hour Meter, 626–1250 Volts.

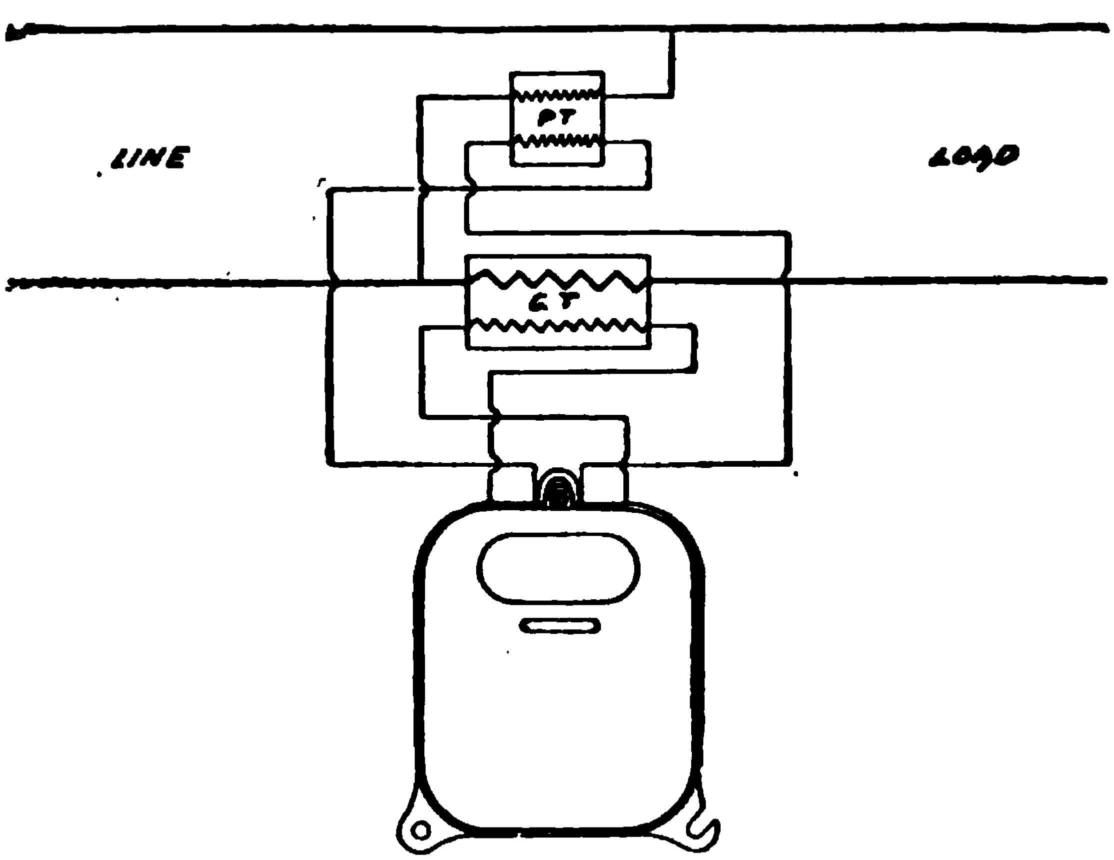


FIG. 598.—External Connections for Types K_1, K_2, K_3, Single phase, 2-wire, Induction Watt-hour Meter, all Capacities, above 625 Volts.

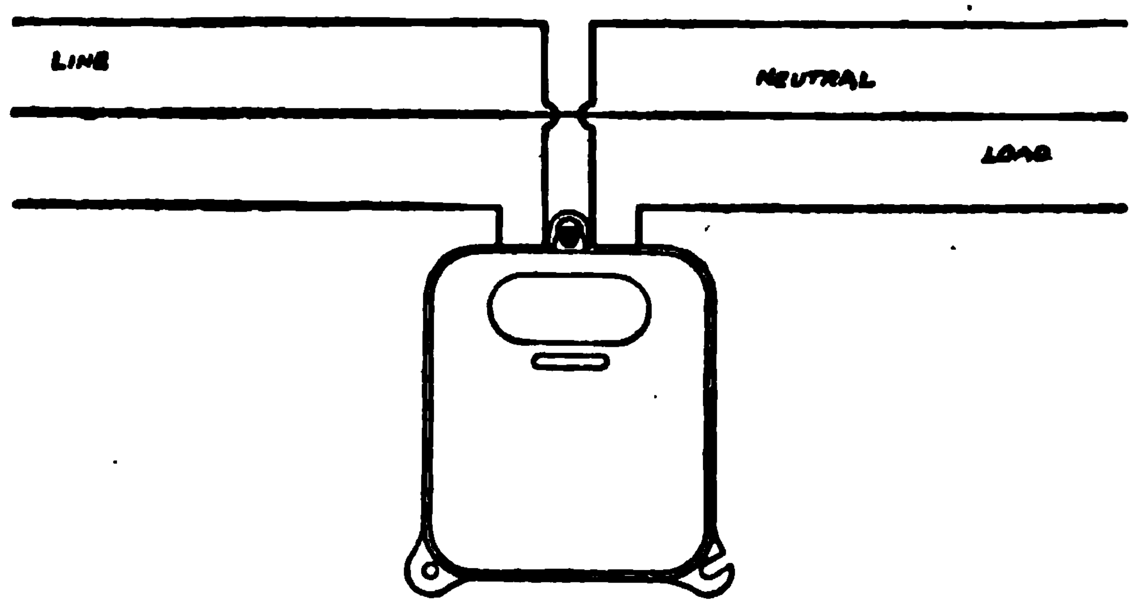


Fig. 599.—External Connections for Types K_1, K_2, K_3, Single-phase, 3-wire, Induction Watt-hour Meter, 5–50 Amperes, 200–500 Volts.

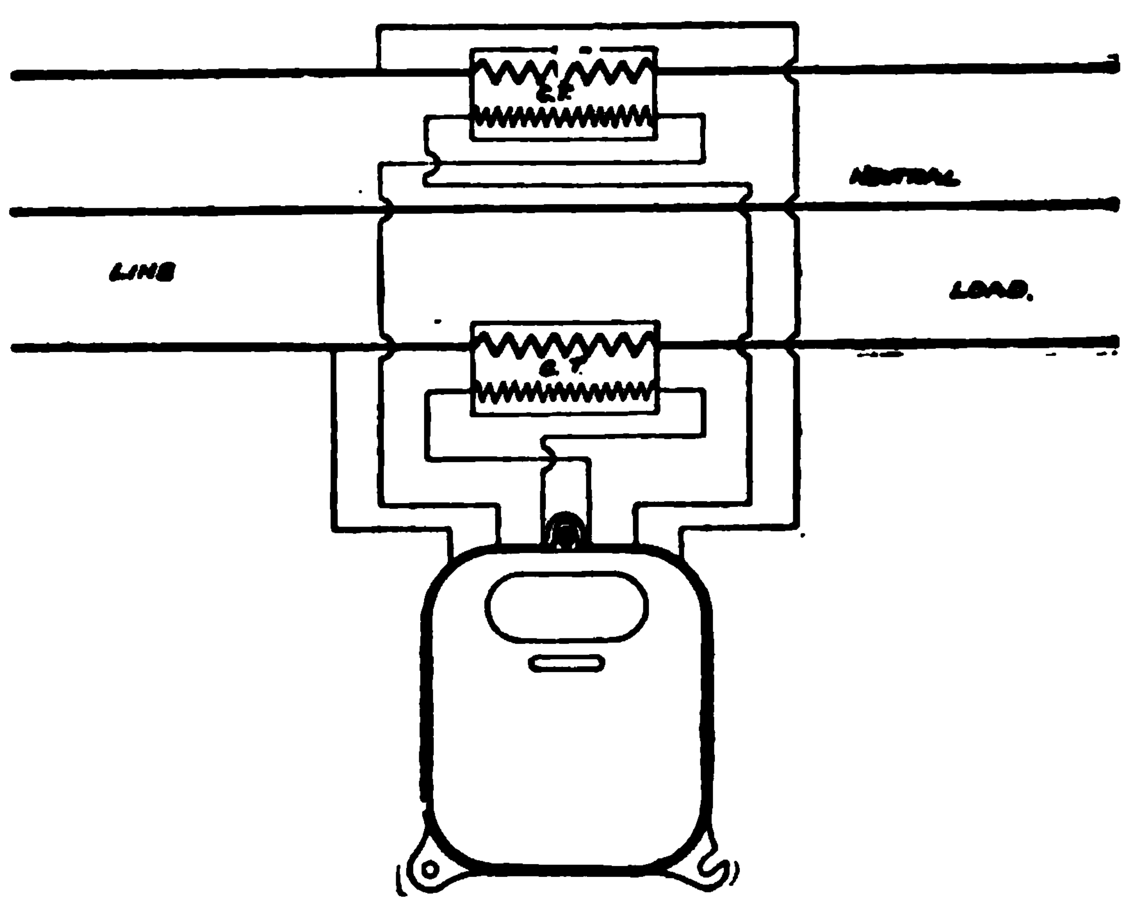


Fig. 600.—External Connections for Types K_1, K_2, K_3, Single-phase, 3-wire, Induction Watt-hour Meter, above 150 Amperes, 200–500 Volts.

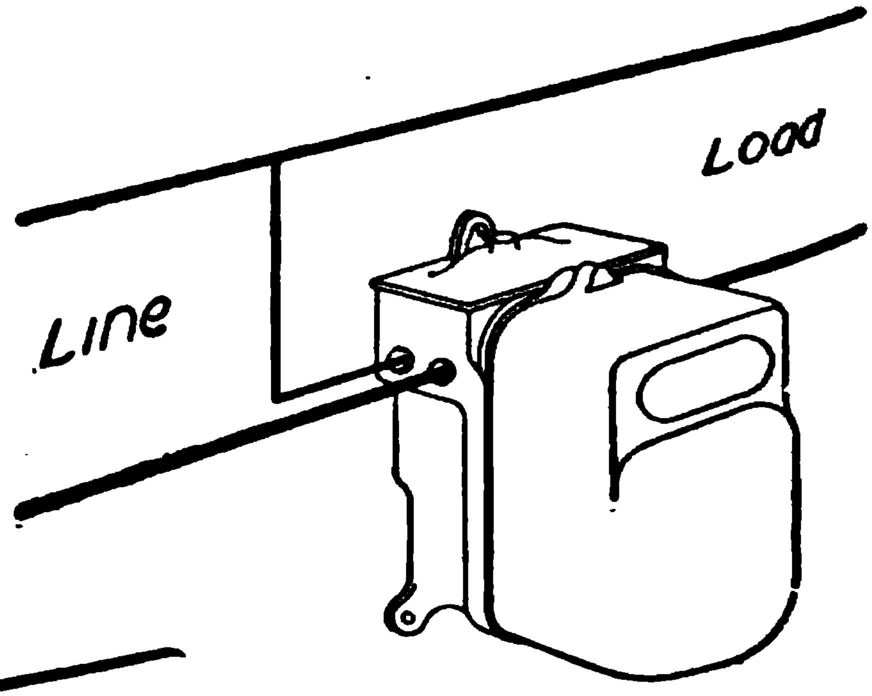


FIG. 601.—External Connections for Types K_1, K_2, K_3, Single-phase, 2-wire, Induction Watt-hour Meter, 75–300 Amperes, 100–625 Volts.

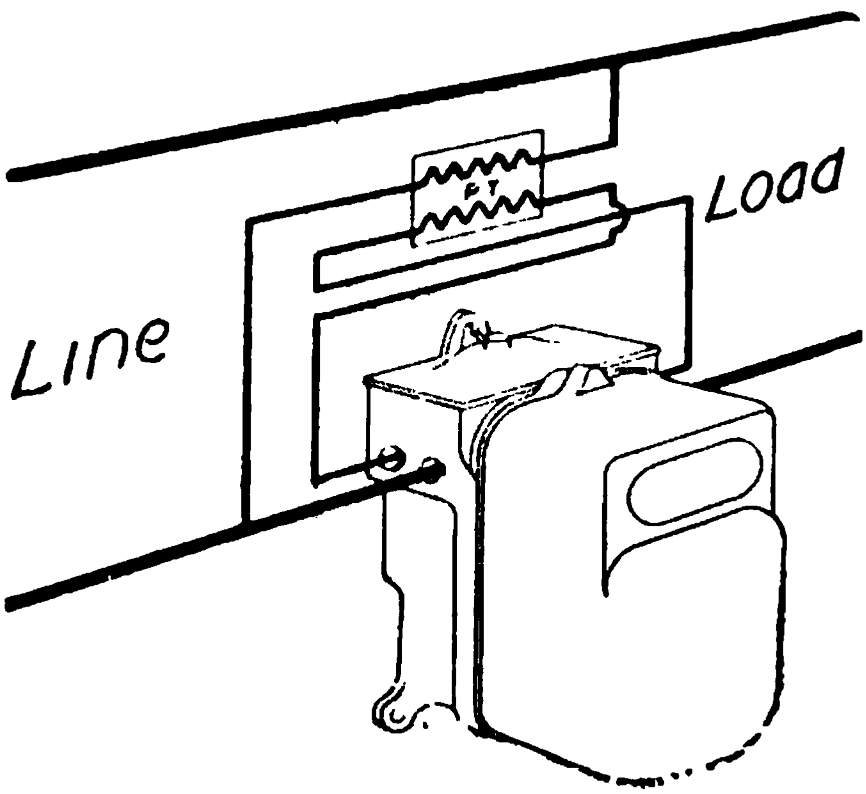


FIG. 602.—External Connections for Types K_1, K_2, K_3, Single-phase, 2-wire, Induction Watt-hour Meter, 75–300 Amperes, 650–1200 Volts.

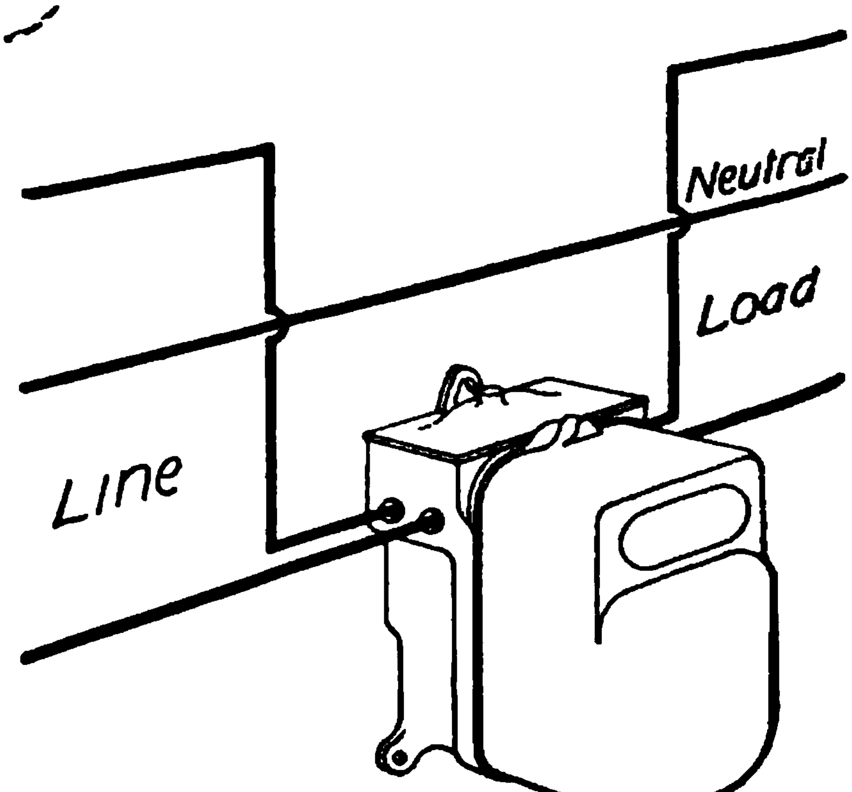


FIG. 603.—External Connections for Types K_1, K_2, K_3, Single-phase, 3-wire, Induction Watt-hour Meter, 75–150 Amperes, 100–500 Volts.

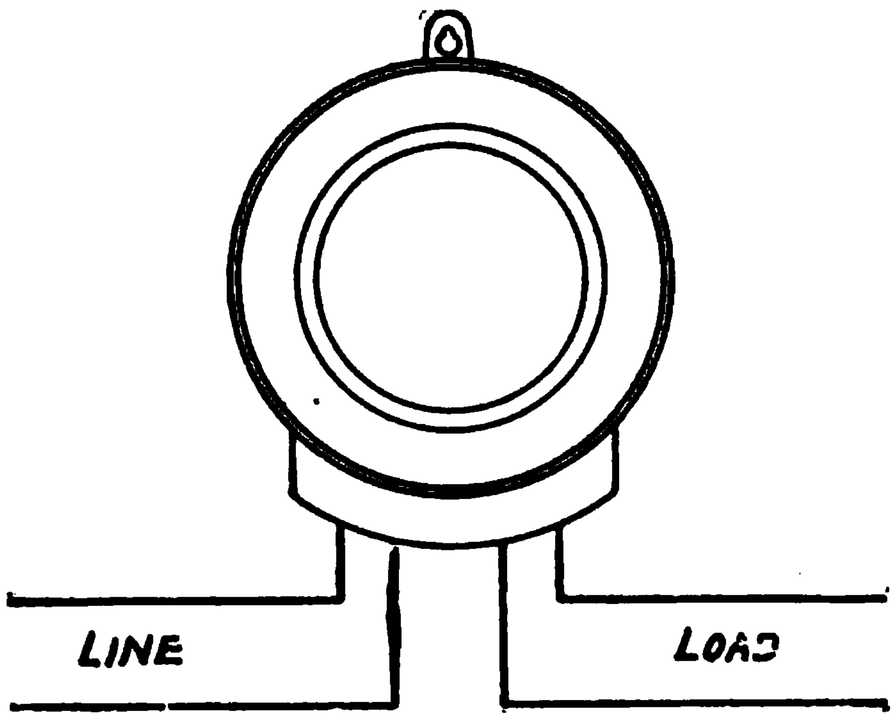


FIG. 604.—External Connections for Type K4, Single-phase, 2-wire, Induction Watt-hour Meters, 5–25 Amperes, 110–220 Volts, 50–140 Cycles.

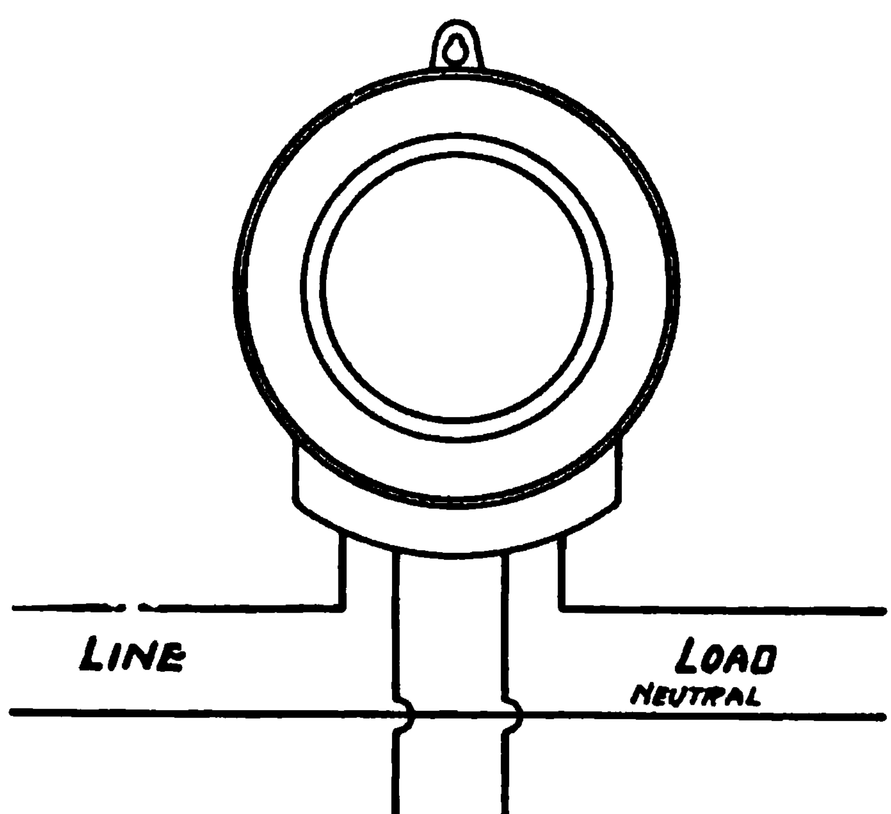


FIG. 605.—External Connections for Type K4, Single-phase, 3-wire, Induction Watt-hour Meters, 5–25 Amperes, 110–220 Volts, 50–140 Cycles.

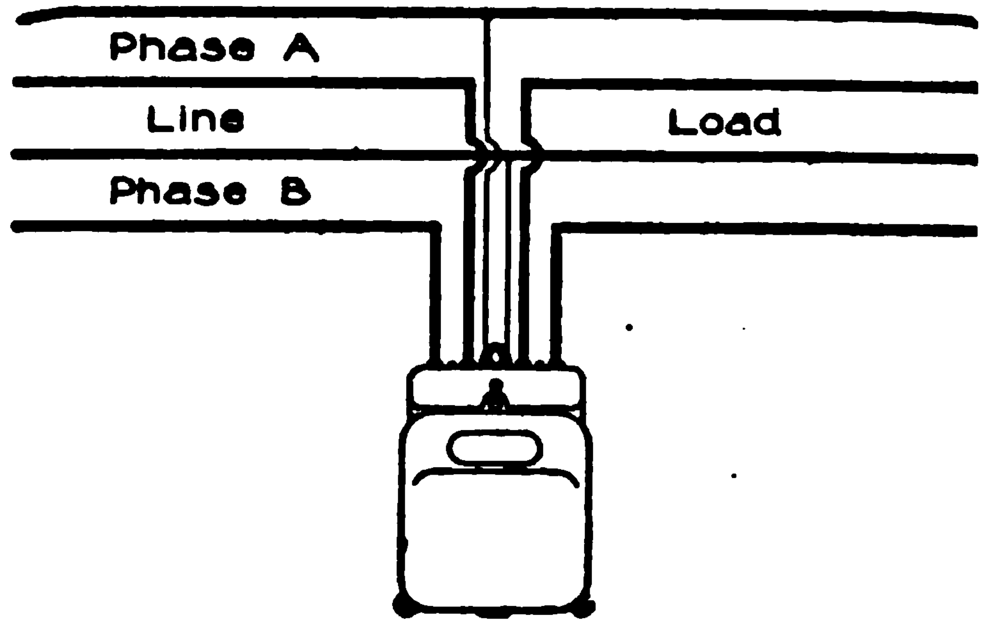


FIG. 606.—External Connections for Type K_1, Two-phase, 4-wire, Induction Watt-hour Meter, below 200 Amperes, 100–625 Volts.

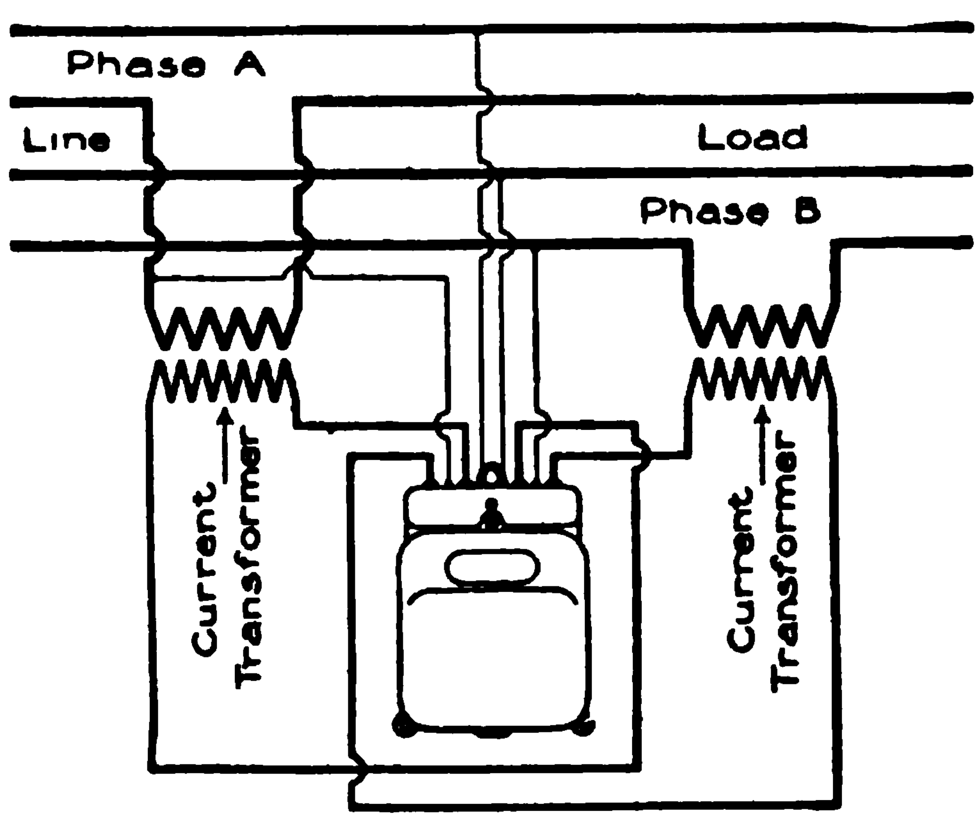


FIG. 607.—External Connections for Type K_1, Two-phase, 4-wire, Induction Watt-hour Meter, above 150 Amperes, 100–625 Volts.

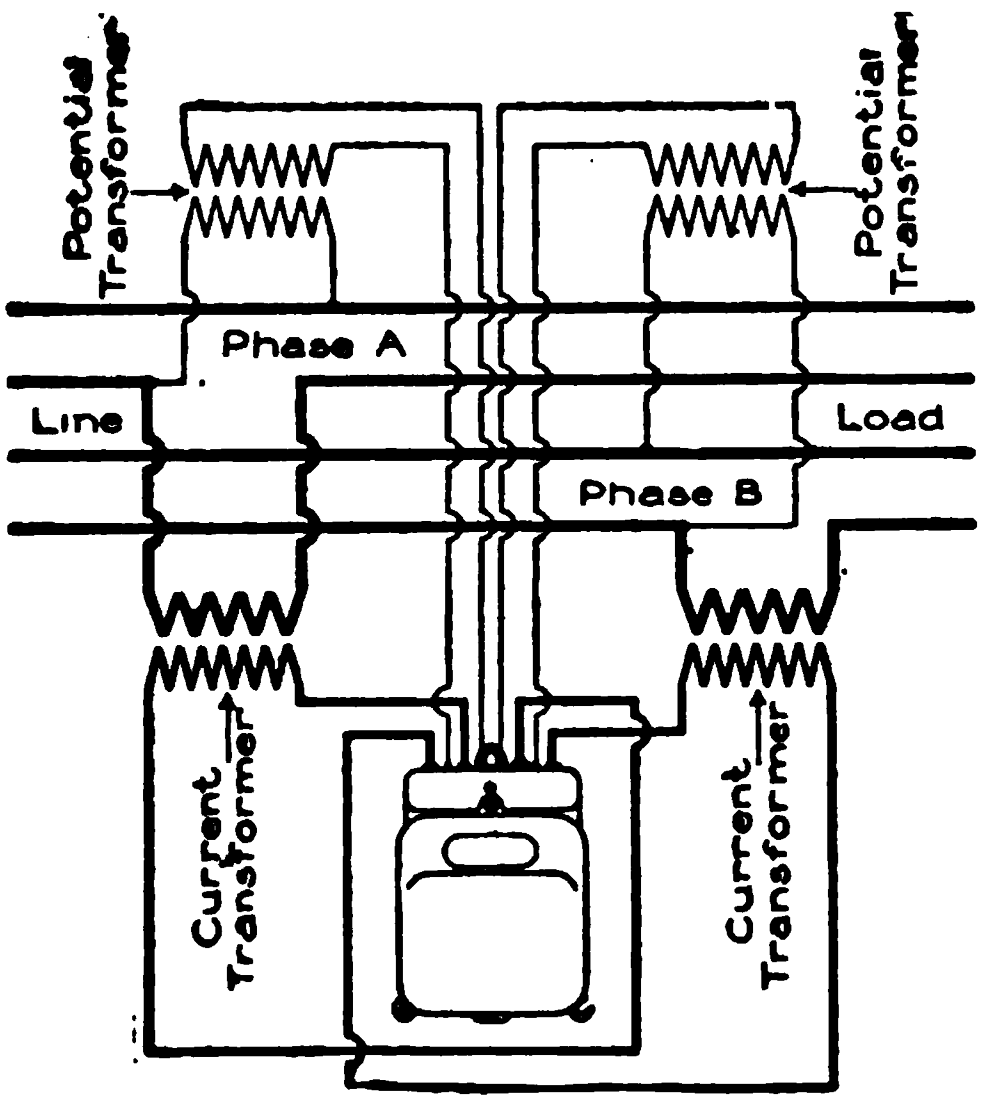


FIG. 608.—External Connections for Type K_1, Two-phase, 4-wire, Induction Watt-hour Meter, all Capacities, above 125 Volts.

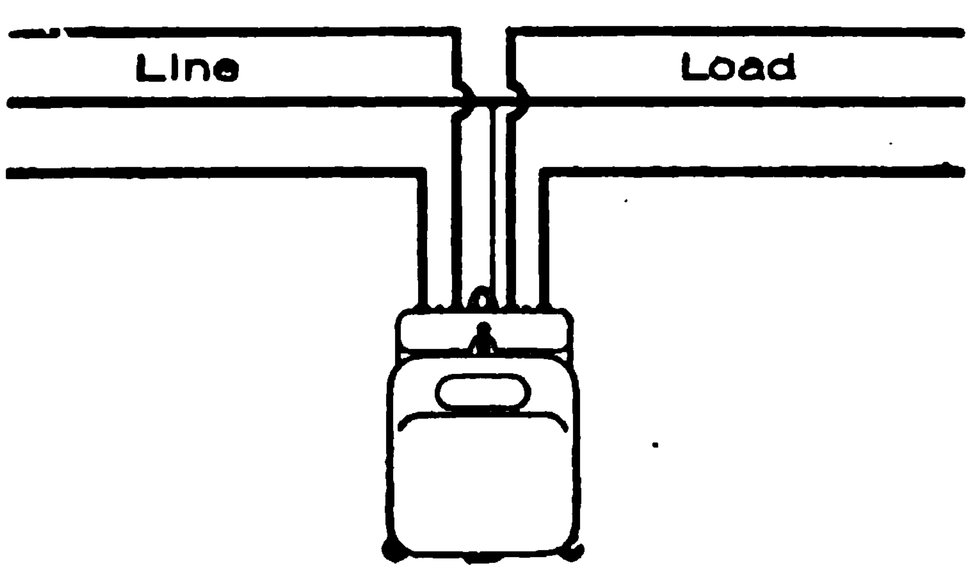


FIG. 609.—External Connections for Type K_1, Two- and Three phase, 3-wire, Induction Watt-hour Meter, below 200 Amperes, 100–625 Volts.

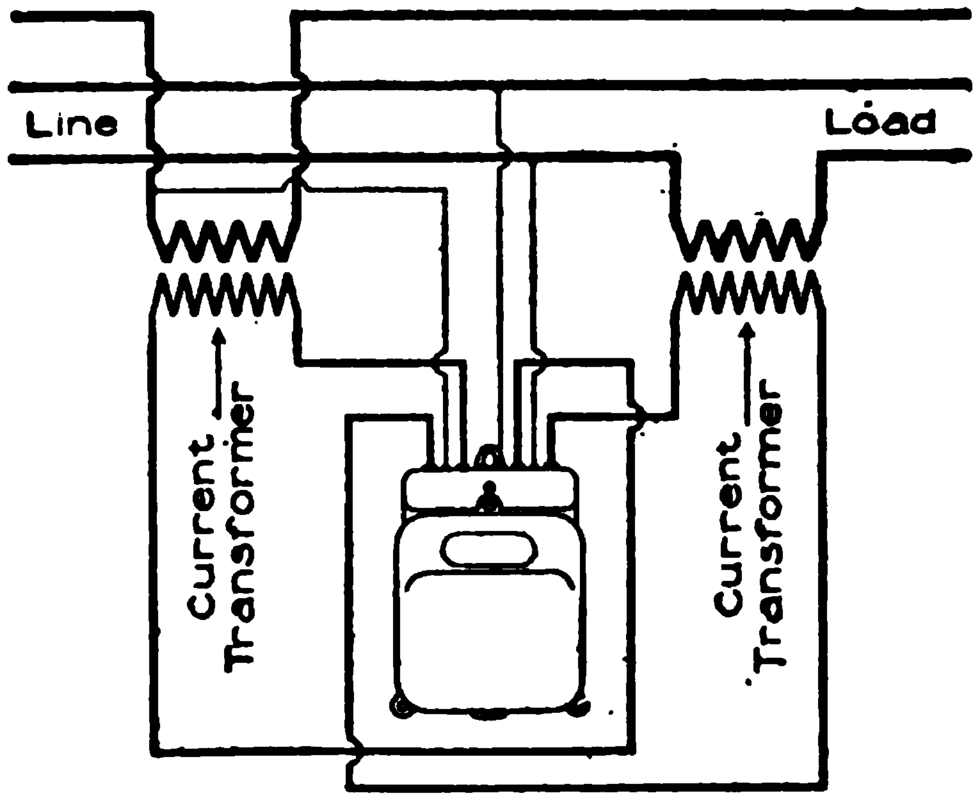


FIG. 610.—External Connections for Type K_1, Two- and Three-phase, 3-wire, Induction Watt-hour Meter, above 150 Amperes, 100–625 Volts.

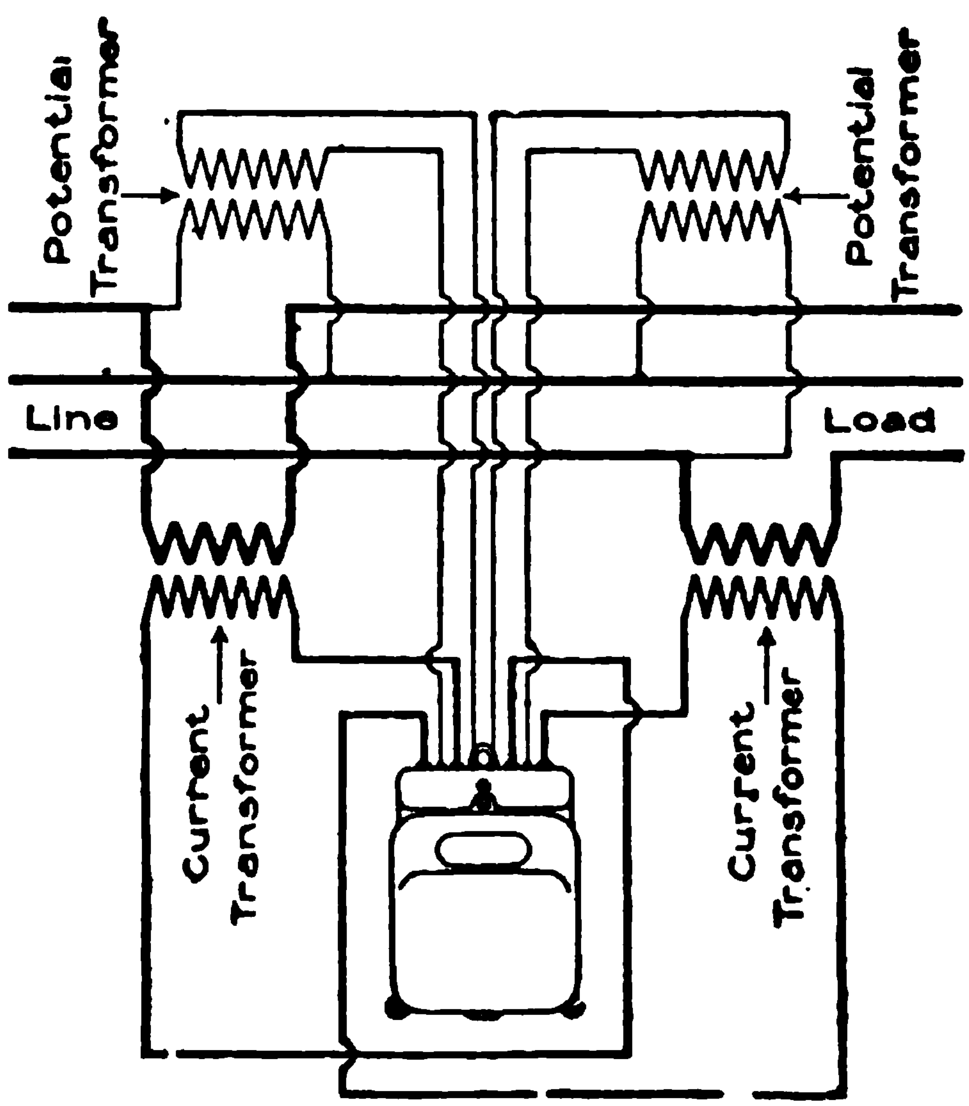


FIG. 611.—External Connections for Type K_1, Two- and Three-phase, 3-wire, Induction Watt-hour Meter, all Capacities, above 625 Volts.

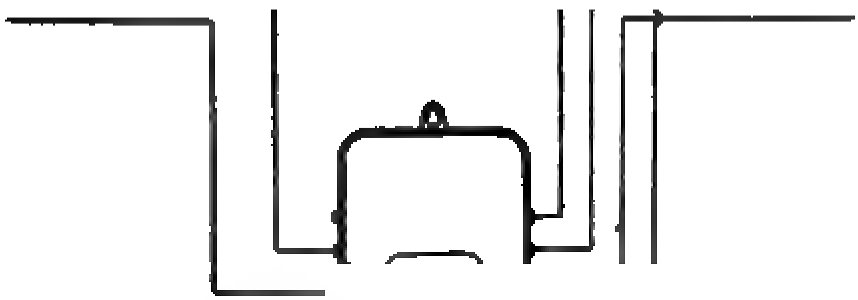


FIG. 612.—External Connections for Type K₃, Two-phase, 4-wire, Induction Watt-hour Meter, below 200 Amperes, 100–625 Volts.

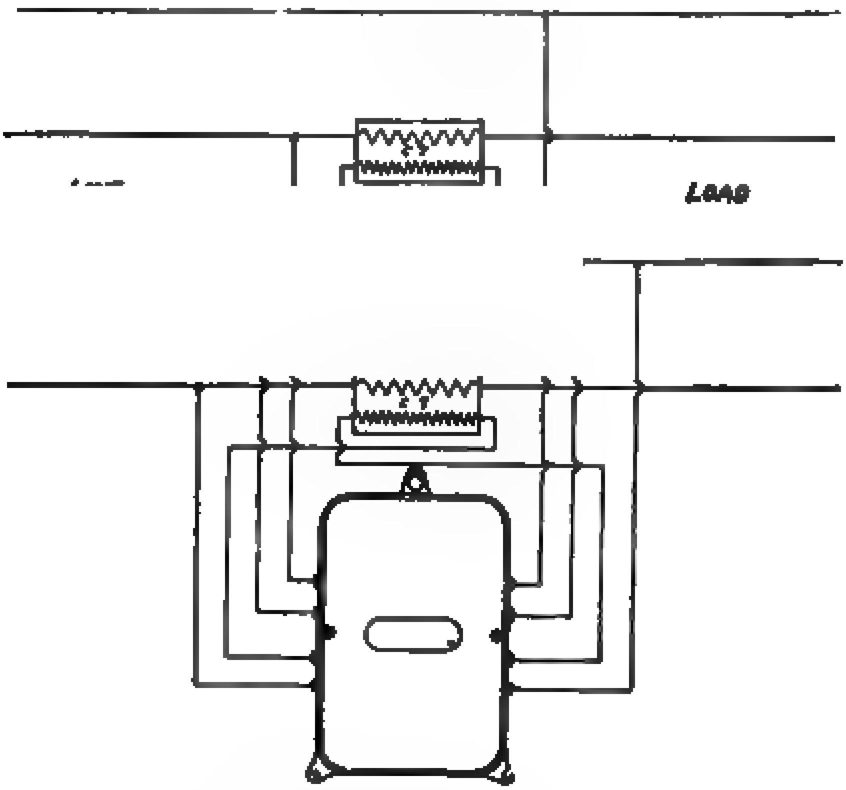


FIG. 613.—External Connections for Type K₃, Two-phase, 4-wire, Induction Watt-hour Meter, above 150 Amperes, 100–625 Volts.

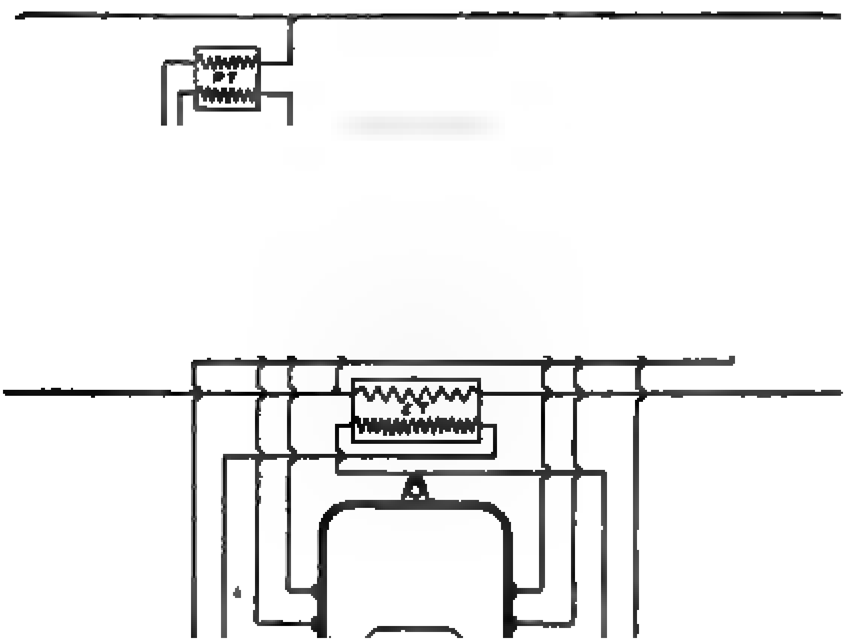


Fig. 614.—External Connections for Type K2, Two-phase, 4-wire, all Capacities, above 625 Volts.

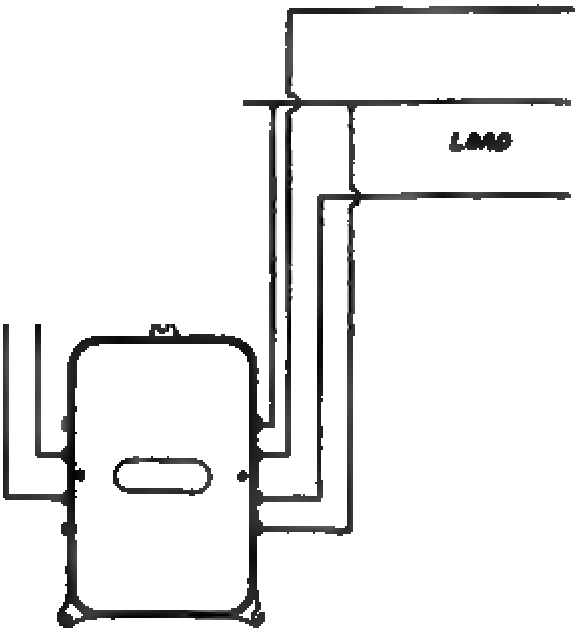


Fig. 615.—External Connections for Type K2, Two- and Three-phase, 3-wire, Induction Watthour Meters, below 200 Amperes, 100–625 Volts.

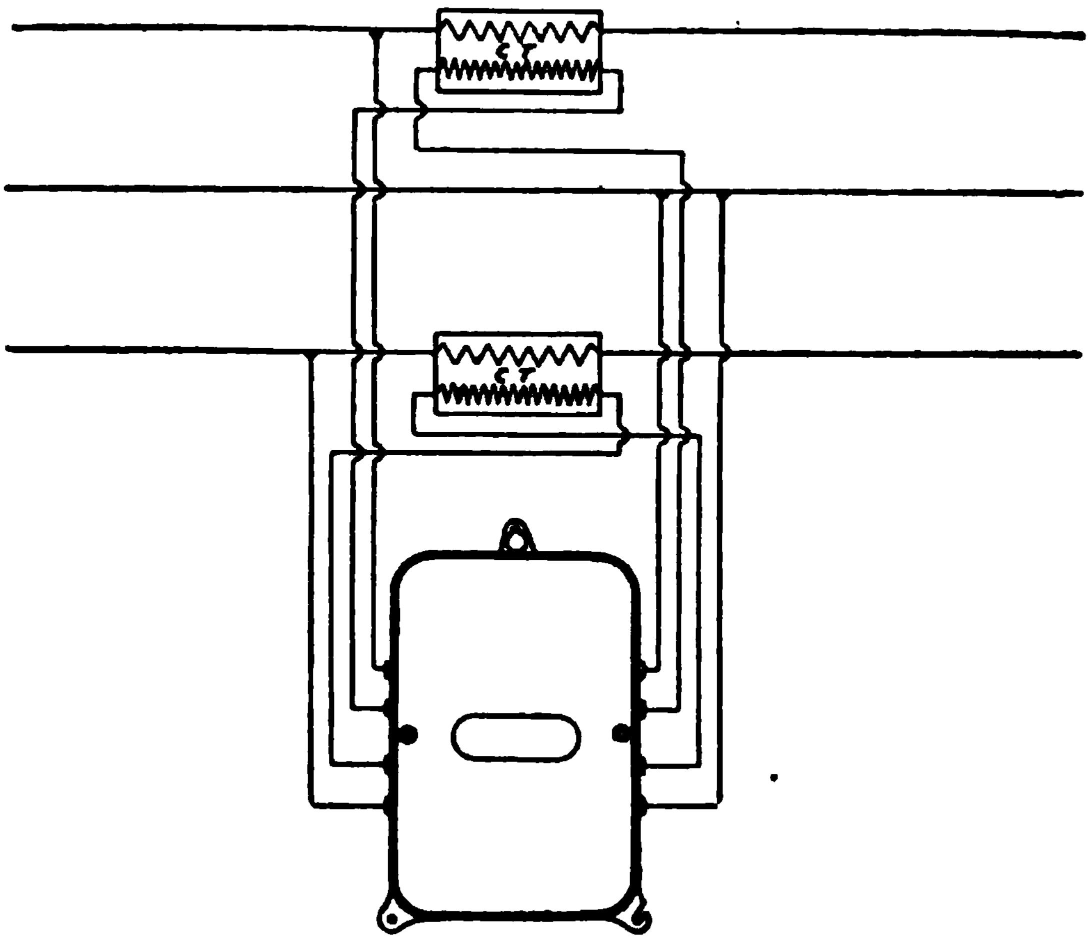


FIG. 616.—External Connections for Type K3, Two- and Three-phase, 3-wire, Induction Watt-hour Meter, above 150 Amperes, 100–625 Volts.

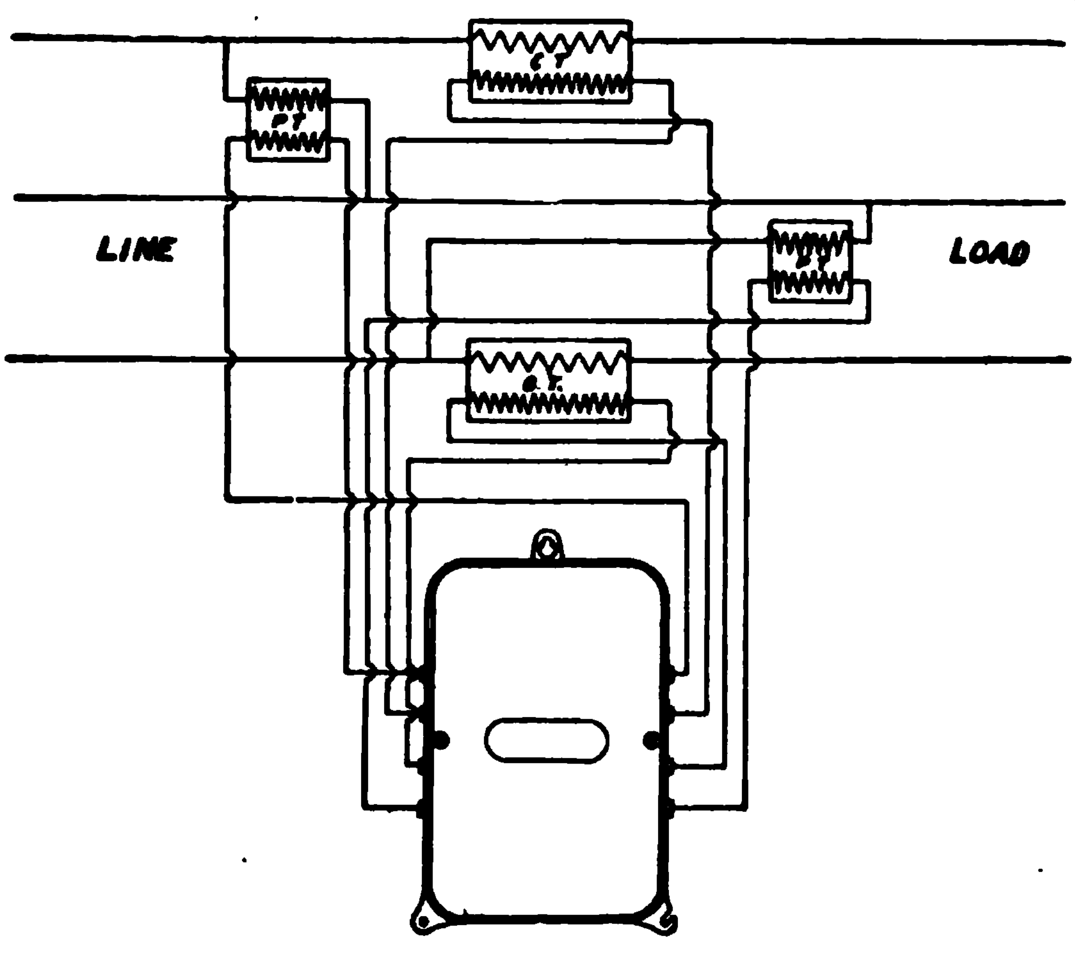


FIG. 617.—External Connections for Type K3, Two- and Three-phase, 3-wire, Induction Watt-hour Meter, all Capacities, above 625 Volts.

Fig. 618.—External Connections for Type K_3, Three-phase, 4 wire, Induction Watt-hour Meter, below 50 Amperes, 100–625 Volts.

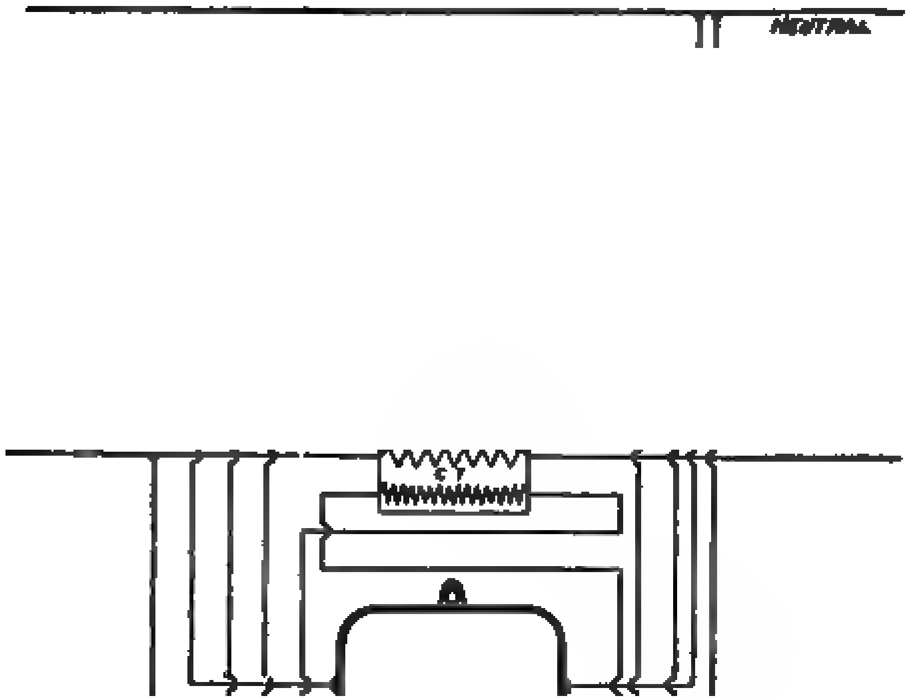


Fig. 619.—External Connections for Type K_3, Three-phase, 4-wire, Induction Watt-hour Meter, above 25 Amperes, 100–625 Volts.

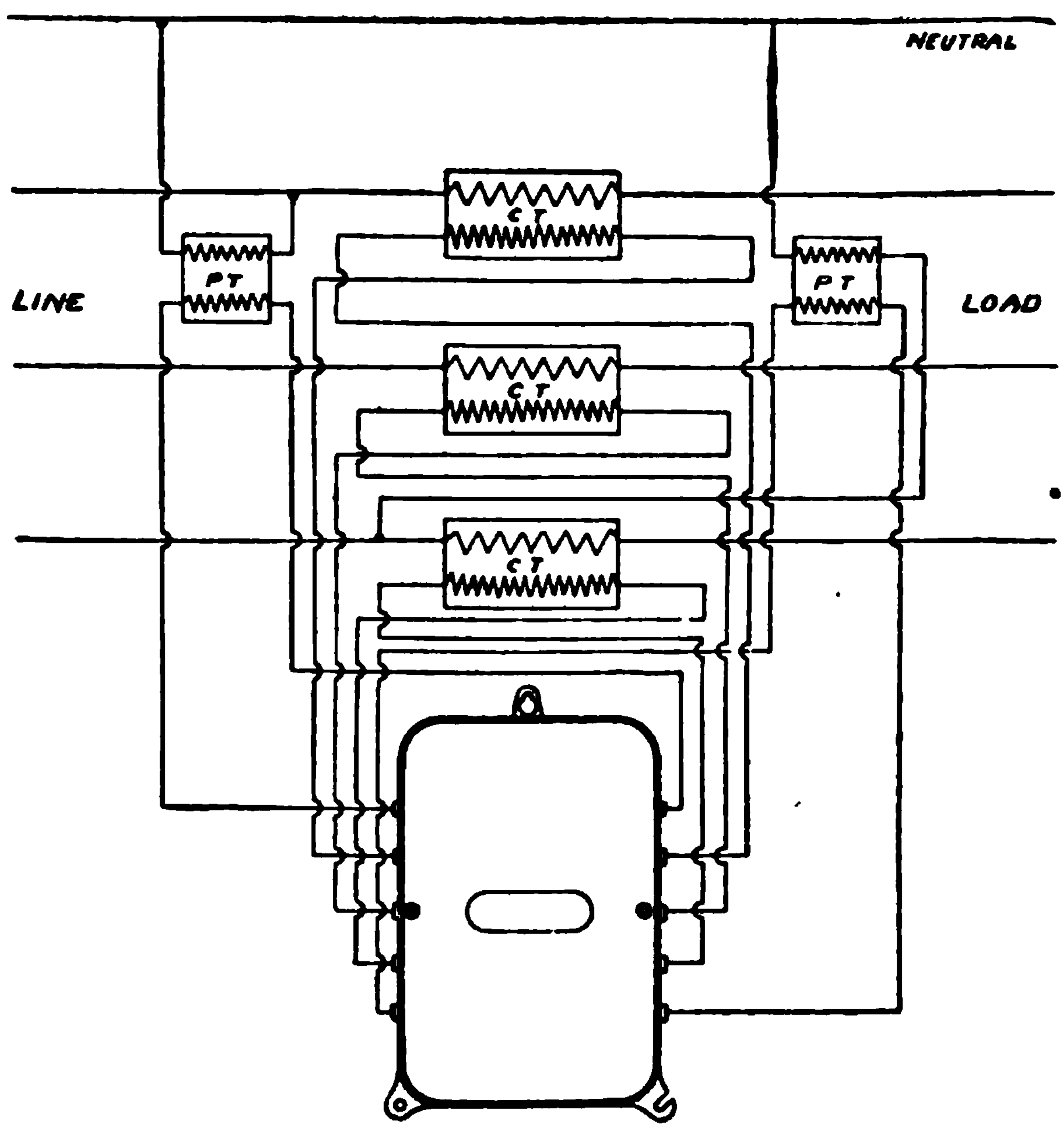


FIG. 620.—External Connections for Type K3, Three-phase, 4-wire, Induction Watt-hour Meter, all Capacities, above 625 Volts.

External Dimension Diagrams

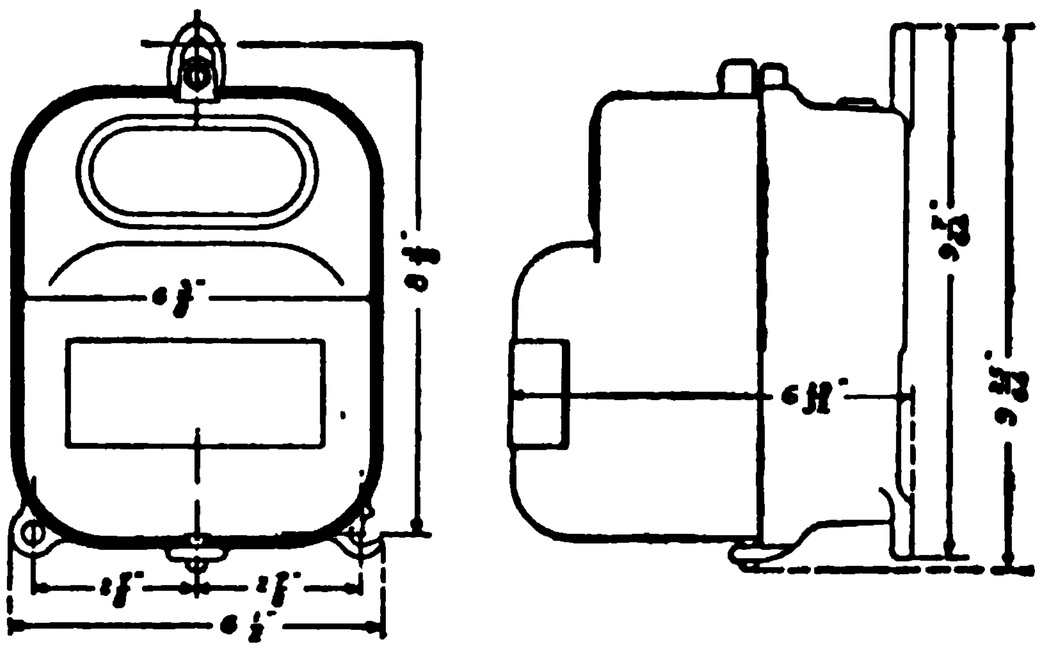


FIG. 621.—Diagram of Dimensions of Types K1, K2 and K3, Single-phase, Induction Watt-hour Meter, 5 to 50 Amperes, and with Current Transformers, above 300 Amperes.

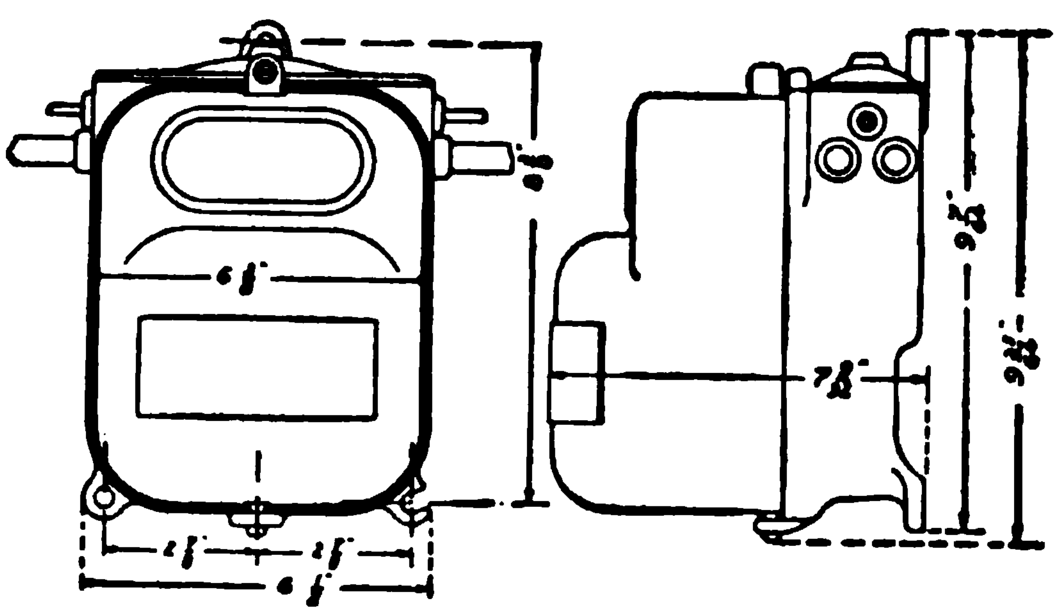


FIG. 622.—Diagram of Dimensions of Types K1, K2 and K3, Single-phase, Induction Watt-hour Meter, 75 to 300 Amperes.

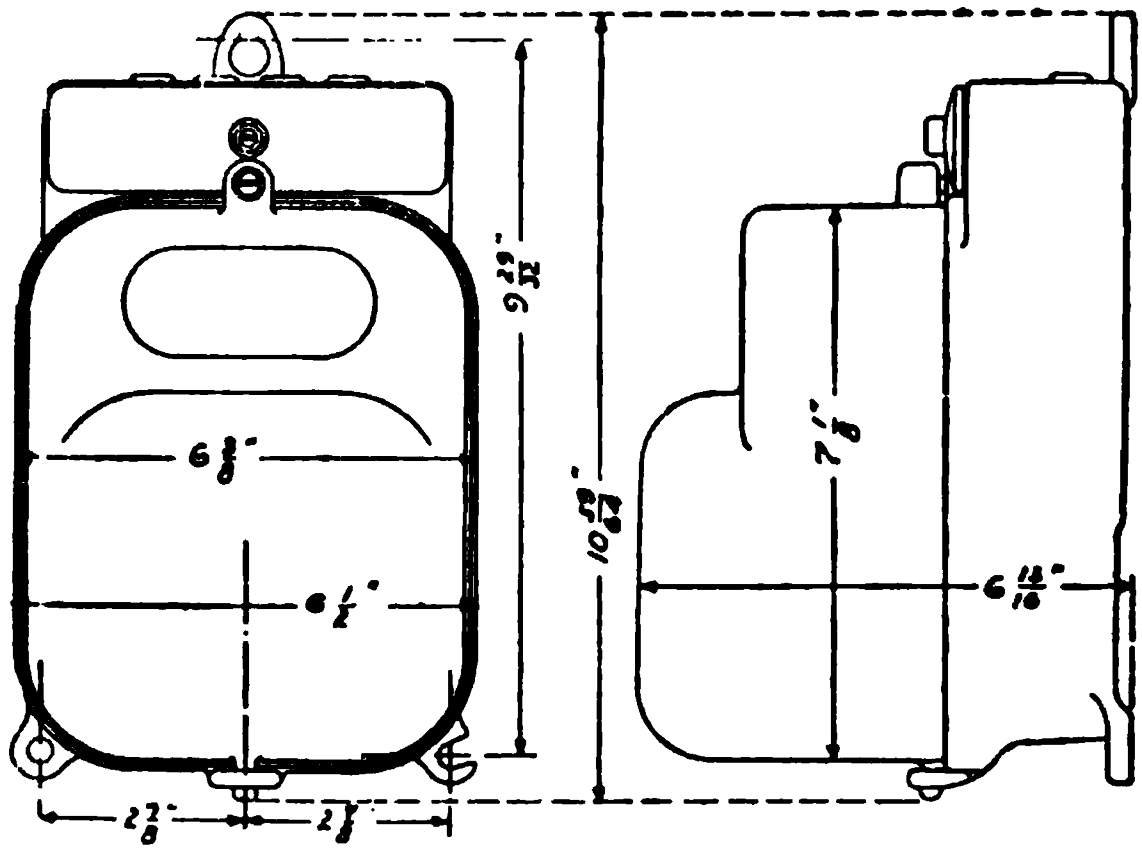


FIG. 623.—Diagram of Dimensions of Types K1, K2 and K3, Single-phase, Induction Watt-hour Meter, 5 to 50 Amperes, and with Current Transformers, above 300 Amperes. Separate Sealed Terminals.

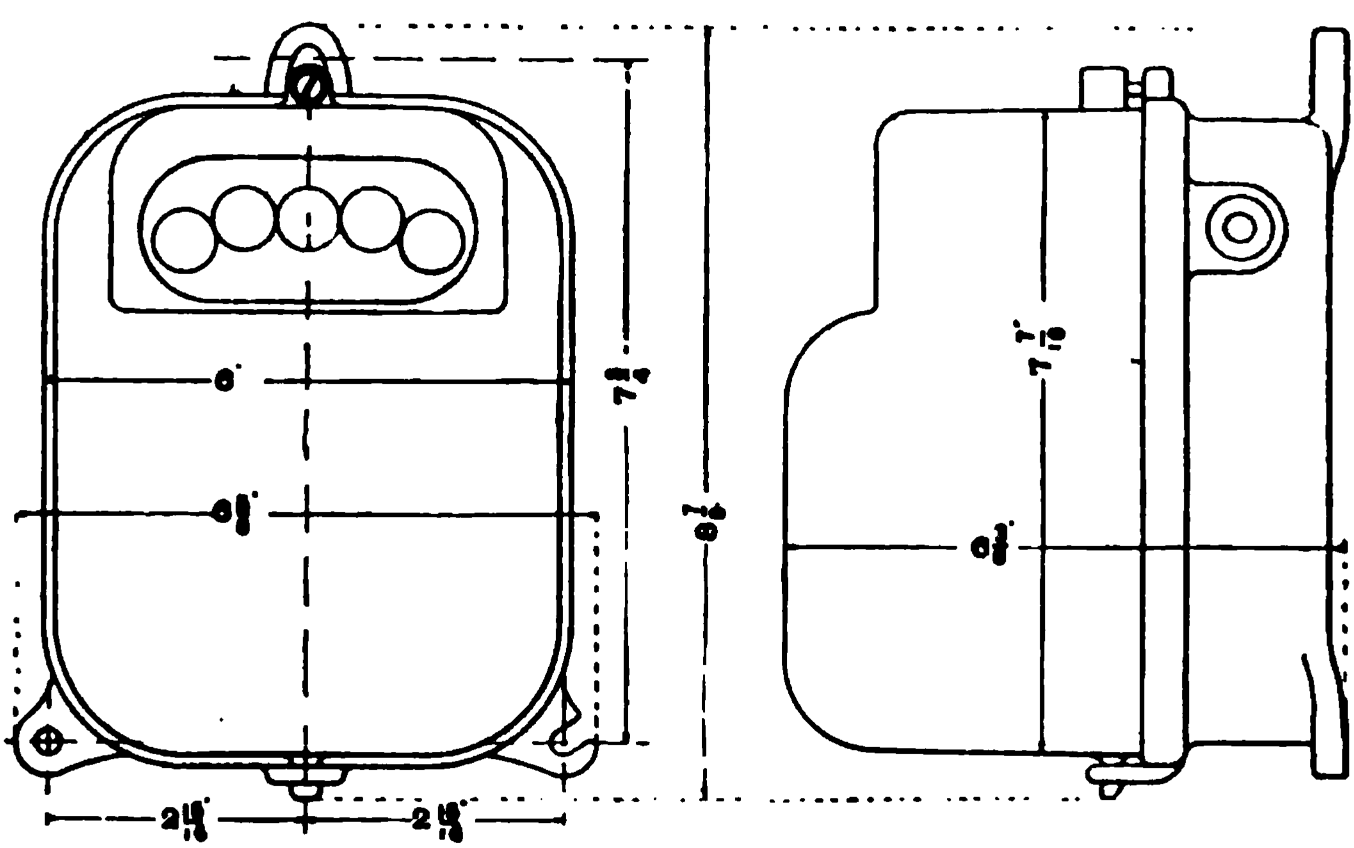


FIG. 624.—Diagram of Dimensions of Type K, Single phase, Induction Watt-hour Meter, all Capacities.

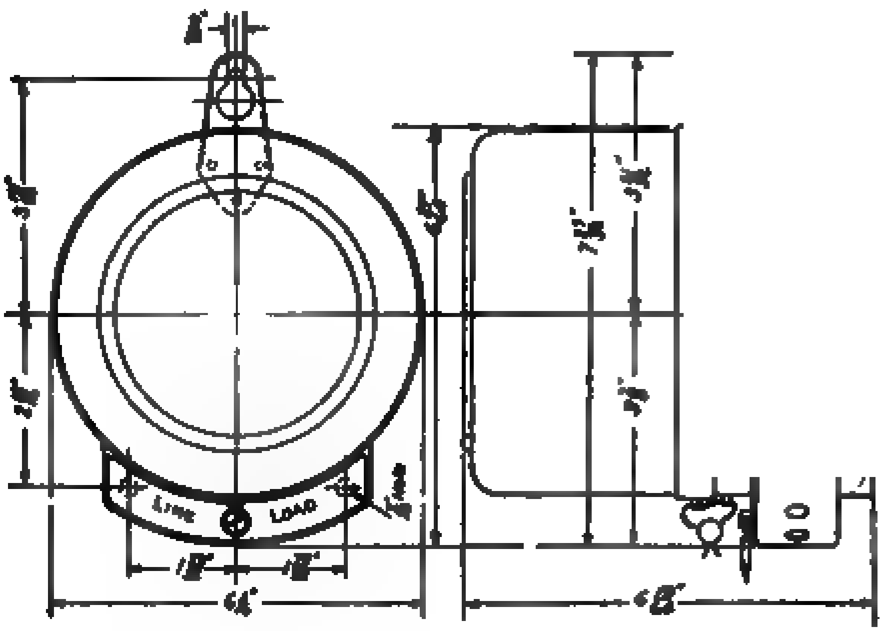


FIG. 625.—Diagram of Dimensions of Type K4, Single-phase, Induction Watt hour Meter, 5 to 25 Amperes, 110 to 220 Volts.

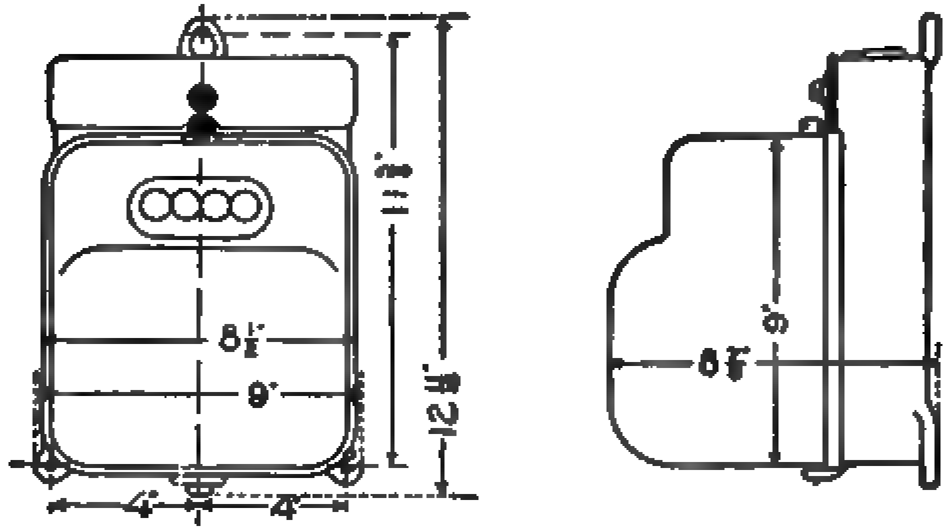


FIG. 626.—Diagram of Dimensions of Type K1, Polyphase, Induction Watt-hour Meter, all Capacities.

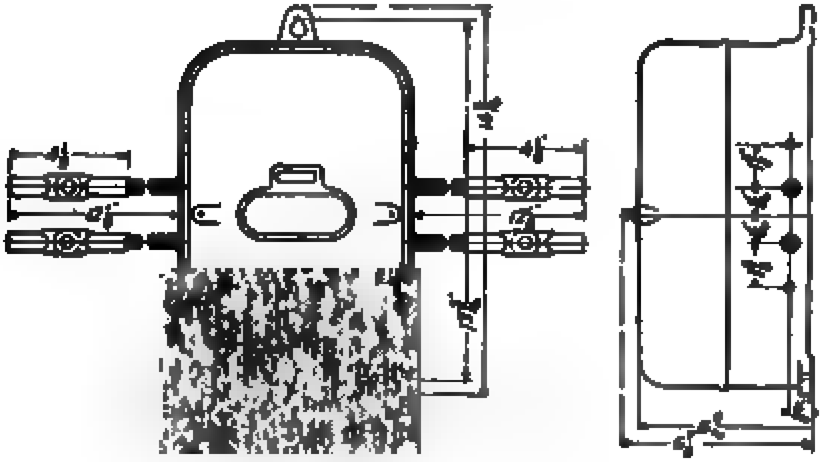


FIG 627.—Diagram of Dimensions of Type K1, Polyphase, Induction Watt-hour Meter, 50 to 150 Amperes, below 625 Volts

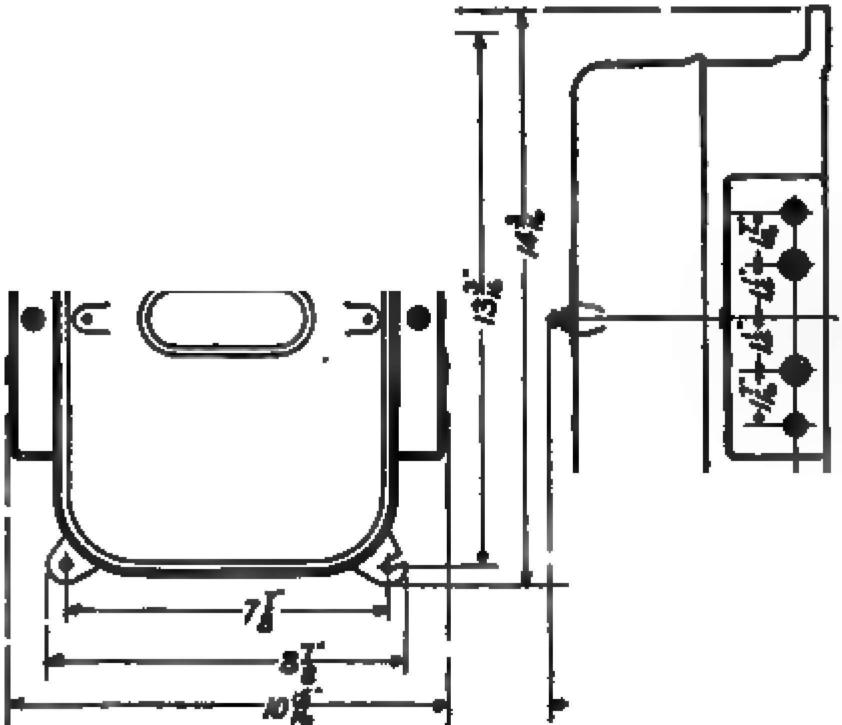


FIG. 628.—Diagram of Dimensions of Type K1, Polyphase, Induction Watt-hour Meter, 5 to 25 Amperes, and above 150 Amperes, all Potentials.

SANGAMO MERCURY MOTOR TYPES OF WATT-HOUR METERS AND AMPERE-HOUR METERS

Continuous and Alternating Current

As the **fundamental principle** and general construction of all Sangamo mercury motor meters is the same, a description of the general mechanical features of the mercury motor meter, with reference in detail to special electrical features of each of the above types, will be given.

All **mercury motor meters** are based on the well-known Faraday disk principle (Fig. 39, p. 60), according to which a metallic disk will rotate if current is passed between its axis and periphery, the path across which the current passes in the disk being subjected to a magnetic field.

Description of Various Types

Type C

The first Sangamo mercury meter, Type C, was brought out in the fall of 1904. This meter was of the same fundamental principle as the present types, but owing to the various defects found with this meter, its manufacture was soon discontinued and it was superseded by the first Type D continuous current meter in the fall of 1905.

Type D, Continuous Current

In the first Type D meter a thin copper disk was completely immersed in mercury in a chamber formed of moulded insulating material, with suitable copper contacts,—imbedded in the insulation at each extremity of a diameter of the chamber,—adapted to carry current in and out from the mercury. The armature was provided with a hollow copper shell, or float, so that the buoyancy of the armature immersed in mercury was sufficient to give the entire moving system,—consisting of the armature inside the chamber and the aluminum damping disk outside,—a slight and positive upward thrust.

In the upper moulded insulation piece, forming the mercury chamber, a steel plate, or ring, was imbedded so that it acted as a return for the lines of force emanating from a potential circuit magnet placed below the chamber and with its pole pieces having their centers on the same diametrical line as the contacts of the mercury chamber. With this arrangement, current passing between the contacts was subjected to the influence of the two fields passing through the disk in opposite directions, and

thus a continuous torque effect was obtained, depending upon the volume of current passing and the intensity of the field. With a field varying proportionally to the voltage and current through the chamber being the load, or a fractional part thereof, a torque was obtained proportional to the power except for the error introduced by the damping effect of the potential circuit field upon the armature itself. The necessary main damping was obtained by the damping disk referred to above, acted upon by two permanent magnets held in the back of the meter and not adapted to be moved with respect to the disk, but having the drag effect of the damping disk and magnets relatively large as compared with that of the potential circuit field on the armature. The error on varying voltage was thus reduced and rotation of the armature, driving the damping disk, was thus practically proportional to the energy passing.

Motion was transmitted from the shaft to a recording train through a worm and worm wheel in the usual manner, and the dials of the original Type D meter read in watt-hours, having five dials, with the first dial for 1,000 watt-hours per revolution of the dial hand.

In the original Type D meter, as in all subsequent ones, spilling of the mercury during shipment or in handling was practically prevented by a construction of the mercury chamber somewhat like an invertible inkwell, a pocket, or space, being provided for the mercury to run into when a meter was turned upside down so that there was very little opportunity for mercury to get out between the shaft and the ring jewel in the cover of the mercury chamber.

Type D, Alternating Current

Shortly after the Type D continuous current meter was brought out, an attempt was made to build an alternating current mercury meter by putting a condenser of suitable capacity in series with the potential coil as used in the continuous current meter; all other features of the meter being as just described. With this arrangement, when there was a certain definite frequency, a balance could be obtained between the capacity of the condenser and the inductance of the potential coil, so that current passing through the potential coil was in phase with the impressed e. m. f., and in that case, as is evident, a true measurement of energy under all condition of power-factor was obtained. This meter, however, suffered an extreme error from very slight variations in frequency, owing to the use of the capacity and inductance balance feature so that after a small number had been manufactured. this type was discontinued for alternating current measurement.

In June, 1906, another form of alternating current meter was developed, this also being called Type D, through a rather unfortunate selec-

tion of classification, but the operation was by means of a small voltage transformer within the meter instead of a condenser. This mode of operation was continued in the Type F meter described below, and as the Type F is the final form in which the transformer type, mercury meter has been manufactured, a further description of the Type D transformer meter seems unnecessary.

Type E, Alternating Current

The above type was further continued in the Type E, alternating current mercury meter, beginning with January, 1907, and the manufacture of this type was continued until the fall of 1907. This was similar in most respects to the Type D transformer alternating current meter, but with some modifications in the armature, adjustments, etc

Type D Continuous Current. (Present Form)

During 1906 and 1907 the Type D continuous current meter was improved in various details until in the spring of 1908 the meter was brought out in its present form as described in detail below, and at the

FIG. 629.—Cross-section of Motor Element of Sangamo Watt-hour Meters.

same time the Type F, alternating current, mercury meter was put on the market. The present Type D meter and the present Type F, are exactly alike in all structural details; in fact, in everything except the arrangements peculiar and necessary to the continuous current and alternating current forms, respectively.

In Fig. 629 is shown a cross-section of motor element of the mercury meters as now made by the Sangamo Company, from which the arrangement of armature, hard wood float, laminated iron return plate. contacts and metal bottom plate will be plainly seen. In this view is also shown the arrangement of middle ring jewel where the shaft passes up from the mercury chamber, with inverted inkwell construction, and the upper bearing, which takes the slightly upward pressure of the moving system. In this cross-section, the laminated magnet of the Type D and Type F meter is omitted for the sake of clearness.

In Fig. 630 is shown the internal connections of this meter, which will give a further idea of the construction.

A.—Copper disk armature, submerged in mercury.

B.—Bridge wire between binding-posts, for main load current. when both sides of the line are carried through the meter.

CT.—Compounding series turns around potential circuit magnet, building up field as load increases, to compensate for falling off in speed otherwise found.

D.—Aluminum damping, or brake disk, controlling speed of meter.

E.—Copper contact ears, imbedded in insulating wall of mercury chamber, leading current into and out from armature.

F.—Hardwood float on armature proportioned to give slight "lift" to entire moving system, when armature and float are immersed in mercury.

H.—Soft steel disk above permanent magnets, riveted to fine pitch screw working in bracket above, so that adjustment of the disk up or down gives variation in damping effect of permanent magnets, and therefore of main speed.

K.—Clamp slider with thumb-screw, for obtaining light load adjustment by moving K to right or left, as may be necessary. K spans and connects parallel wires of light load adjustment, BR and RR^1.

MM.—Powerful permanent magnets, acting on disk D, giving main speed control for meter.

N.—High resistance heavy wire, forming part of series adjustment between armature and any shunt with which meter may be used. to set drop through meter correct for drop of the shunt.

P.—Spirally laminated soft steel ring, moulded in mercury chamber above the armature space, to act as a return for magnetic lines of force from and to energizing magnet below.

R.—Resistance card unit, in series with potential circuit coils; in 110 volt meters one card is used, in 220 volt meters two cards, or one card and a thermo-couple. In 500 volt meters, R is a large amount

of resistance, contained in a ventilated iron box exterior to the meter.

BR.—Small brass wire, connected to ingoing end of potential cir-

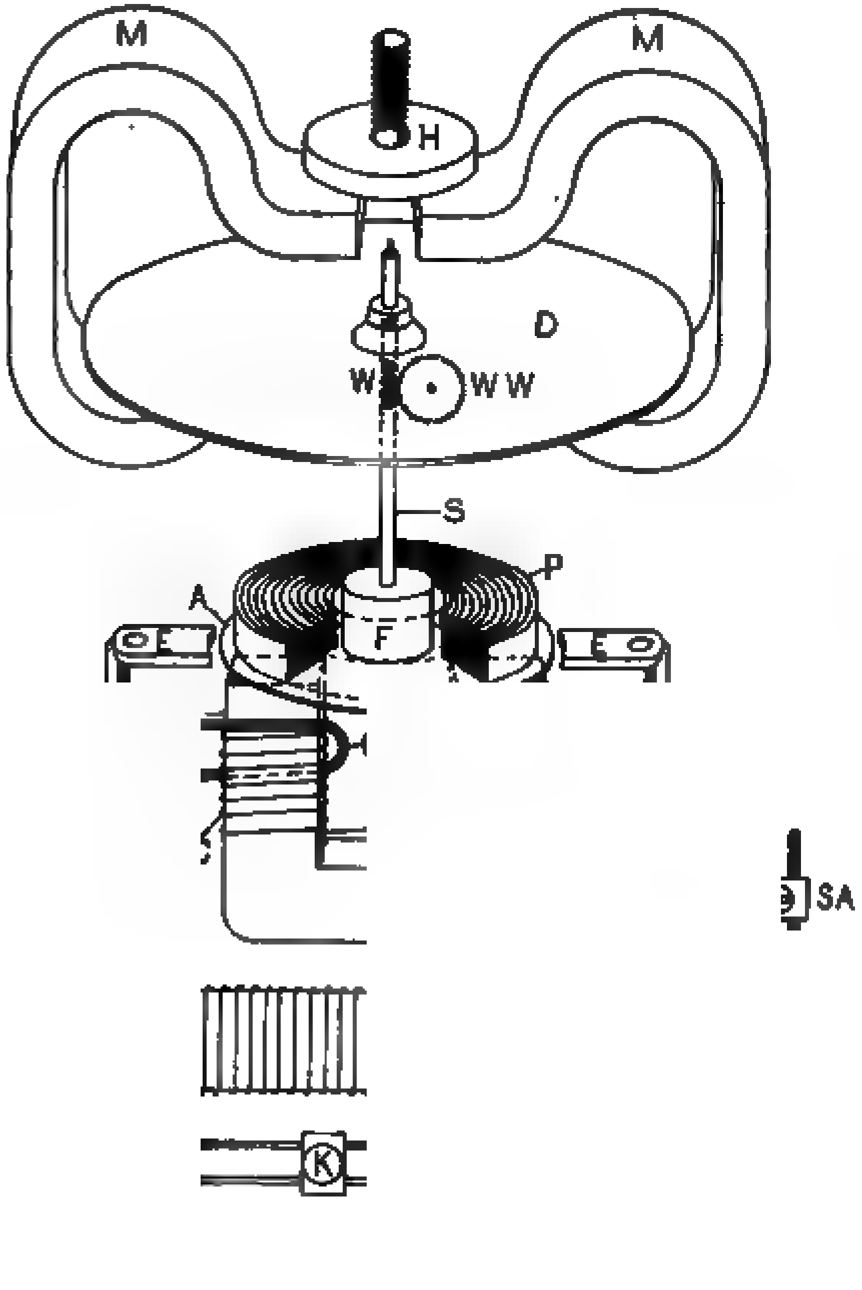


FIG. 630.—Internal Connections of Sangamo, Type D, Continuous Current Watt-hour Meter

cuit coils, and forming, with RR' and the slider K, the light load adjustment device of meter.

RR.—Small wire of high resistance, having opposite ends connected to ears EE by copper wires of low resistance. Current ener-

gizing the potential circuit coils SC passes from RR^1 through K to BR, and thence to the coils, and if K is near end of RR^1 and BR the least compensation is obtained; if near right end, maximum light load conmpensation is obtained.

S.—Shaft or spindle of moving system. In actual meter, S is divided, the lower shaft carrying armature A, and the upper shaft damping disk D.

SA.—Series resistance adjustment, for setting meter to correct drop for shunt, in all capacities over 10 amperes.

SC and SC^1.—Potential coils, each wound with many thousand turns, connected normally in series.

TT.—Binding posts, in connecting box at bottom of meter.

Y.—Laminated soft steel yoke, carrying coils SC and SC^1, and giving a powerful and concentrated magnetic field on the armature.

W.—Worm driving recording dial train.

WW.—Worm wheel on first shaft of recording dial train, driven by W.

The lower end of the shaft in the mercury chamber is located by a guide ring, which, until recently, has been of steel, but at this time and in the future will consist of a ring jewel.

The outer shaft carrying the aluminum damping disk is located on and driven by the armature shaft through an insulating coupling The proportioning of the buoyancy of the armature in the mercury to the weight of the entire moving system is such that a very light pressure, about 3 grams, or $\frac{1}{10}$ of an ounce, is exerted on the upper bearing. The upper bearing is held in such a way as to be closely adjusted, and to give a slight end play, about .02 of an inch, to the moving system.

In the continuous current meter, the U-shaped yoke is energized by a pair of potential coils. Behind the potential coils, in 220 volt and 550 volt continuous current meters and in some types of 110 volt meters. is the thermo couple compensating device for light load, this being two strips of dissimilar metal joined together and surrounded by a heating winding of resistance wire, in series with potential coils of the meter in all types where the thermo couple is used. The purpose of the thermo couple is to pass a low potential current through the armature in order to give the slight initial torque necessary to overcome bearing friction. etc. The thermo couple is so arranged that the current set up in it will always pass from left to right through the armature chamber, no matter which way the load current passes. Therefore, in Type D meters having the thermo couple compensation it is necessary always to connect a meter with the incoming terminal positive. In most 110 volt meters made

during the last two years, the thermo couple has been omitted so that the meter may be connected with either the positive, or negative, incoming, and in this case light load compensation is obtained by the method of passing more, or less, of the small current taken by the potential coils, through the disk of the meter, thus giving an initial torque proportional to the amount of such current passing.

In capacities above 10 amperes, Sangamo continuous current meters are operated with shunts of various types, but in general arranged so that 10 amperes of current will pass through the meter with full load through the shunt. In such meters a proper ratio is used in the recording train, corresponding to the ratio between total current and the amount shunted

Fig. 631.—View of Sangamo, Type D, Continuous Current, Switchboard Watt-hour Meter.

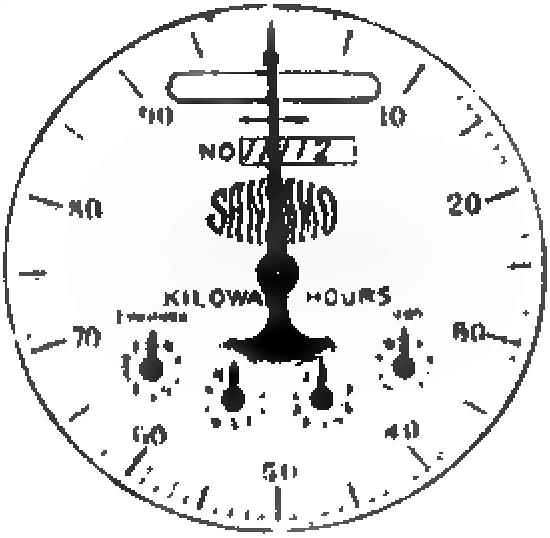


Fig. 632.—Circular Dial Face Used with Sangamo Watt-hour Meters.

through the meter, so that the dials will read directly in kilowatt-hours. On account of the absence of series windings in Sangamo meters, the drop between main and binding posts at full load on a 10 ampere meter is less than .03 volt. The usual standard drop for shunted capacities is 75 millivolts at full load (Figs. 631 and 632).

The **main load adjustment** in the Type D and other Sangamo mercury motor meters is obtained by shunting more or less of the field between the upper poles of the two damping magnets, a soft iron disk being provided for this purpose so that when screwed up and down on its supporting screw, an adjustment for main speed is secured.

Light load adjustment in the continuous current meter has already been described.

The dial faces on all Sangamo mercury watt-hour meters have four dials. On registers for meters of ordinary size the reading is direct; the

first dial being 10 kilowatt-hours per revolution of the dial hand, etc. For very large capacity meters the register readings are increased, having the words "multiplied by 10" and "multiply by 100" below the words "kilowatt-hours" (Fig. 633). On the damping disk of all

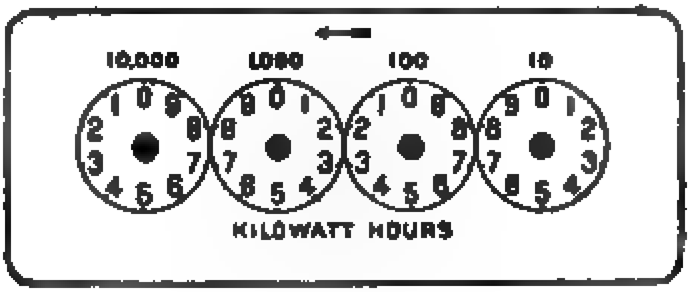


Fig. 633—Dial Face of Sangamo, Continuous Current Watt-hour Meters

mercury meters is stamped the test constant K_t, expressed in watt-seconds K_w instead of watt-hours, per revolution of the disk.

Type D and Type F regular service meters are furnished with either a pressed steel cover with glass front, as shown in Fig. 634, or with a full pressed glass cover.

Fig 634—Sangamo, Type D, Continuous Current Watt-hour Meter

The connection box, as on all Gutmann and Sangamo meters, is below the meter, being provided with a swinging door arranged to be sealed at the lower right hand corner. This, when dropped down, gives access to the binding posts within. The standard connection box, except for 500 volt continuous current meters, has four binding posts, but the latter

has three, two for load and one for potential connection to the external resistance box.

The following is a collection of data relative to the performance of Type D continuous current watt-hour meter of the present form:

Full load speed—5 amp., 12½ rev. per min.; all larger, 25 rev. per min.

Torque at full load of 1,000 watts—10 amp., 110 volts, 55 mm-g.

Weight of moving element—32 g. *in air*, or when immersed in mercury in meter—3 g.

Ratio of torque to weight—18 approx.

Volts drop in series coil at full load—5 and 10 amp., .03 volt. Shunted capacities, shunt drop—.075 volt approx.

Watts lost in series coil at full load—10 amp. meter—.3 watt. (Including shunt); 100 amp. meter—7.5 watts.

Loss in potential circuit—potential coil current, .045 amp. Loss in 110 volt meter, 5 watts; 220 volts, 10 watts, etc.

External resistance of potential circuit; 110 volt meters, 450 ohms, 220 volt meters, 2,650 ohms, 500 to 600 volt meters 10,000 to 13,000 ohms.

Size wire—No. 36 Ferro Nickel.

Potential field coils—2 coils, each 7,000 turns No. 36 copper, in series. Res. cold 1,800-1,900 ohms.

Testing Formula:

K = disk constant = watt-seconds per revolution.

W = load in watts.

S = correct time for one revolution in seconds.

Then $S = \frac{K}{W}$ and

error = observed time (S^1), less S.

$$\text{Per cent error} = \frac{S^1 - S}{S^1}$$

If quantity minus, meter fast.

If quantity plus, meter slow.

The test constants, gear ratios, and so forth, for this type of meter are given in Chapter XV.

The size of holes in binding posts for meters of 5 amperes capacity is 0.166 inches and for larger capacities it is 0.27.

Date of original production, November, 1905; present form May, 1908.

Type F

The mercury motor element of the Type F meter is exactly the same as described for the Type D except that the armature disk is punched

out to form a number of narrow radial arms, this being done to reduce the effect of the secondary currents induced in the disk by the alternating series field.

In the Type F meter there is a small internal voltage transformer, having its high-tension winding connected across the line and with a heavy single-turn low-tension winding adapted to pass a current of large volume and low potential through the armature in the mercury chamber (Fig. 635).

A.—Copper disk armature submerged in mercury.

AS.—Auxiliary secondary winding on transformer N of a few turns giving current for light load compensation.

B.—Bridge wire between middle binding posts.

D.—Aluminum damping or brake disk.

E.—Copper contact ears, leading current into and out from armature.

F.—Hardwood float on armature, proportioned to give slight lift to entire moving system when armature and float are immersed in mercury.

FC.—Series coils, energizing field magnet Y proportional to load, wound with different sizes of wire, and number of turns, according to capacity of meter.

H.—Soft steel disk above permanent magnets, riveted to fine pitch screw working in bracket above, so that adjustment of the disk up or down gives variation in damping effect of permanent magnets, and therefore, of main speed.

J.—Dividing point in lead from AS,—one wire going right-handed around the poles of yoke Y to give forward starting or compensating effect, the other wire going around in reverse direction, to give backward rotative effect:—the other ends of these two wires are carried to the ends of resistance wire RR^1, of light load adjustment.

K.—Clamp slider with thumb screw, for obtaining light load adjustment, moving K to right or left, as may be necessary. K spans and connects parallel wires of light load adjustment, BR and RR^1.

M. M.—Powerful permanent magnets, acting on disk D, giving main speed control for meter.

MS.—Main secondary of transformer N, of copper strap,—connected to armature chamber at EE by heavy wires, so as to pass large volume of current, at low potential, through A.

N.—Small transformer in meter, having its primary connected across the line, up to 250 volts, and with secondary as described above.

P.—Spirally laminated soft steel ring, moulded in mercury cham-

ber above the armature space, to act as a return for magnetic lines of force from and to energizing magnet below.

PT.—Primary of small transformer N,—of 3,000 to 12,000 turns very fine wire,—according to voltage and frequency of circuit.

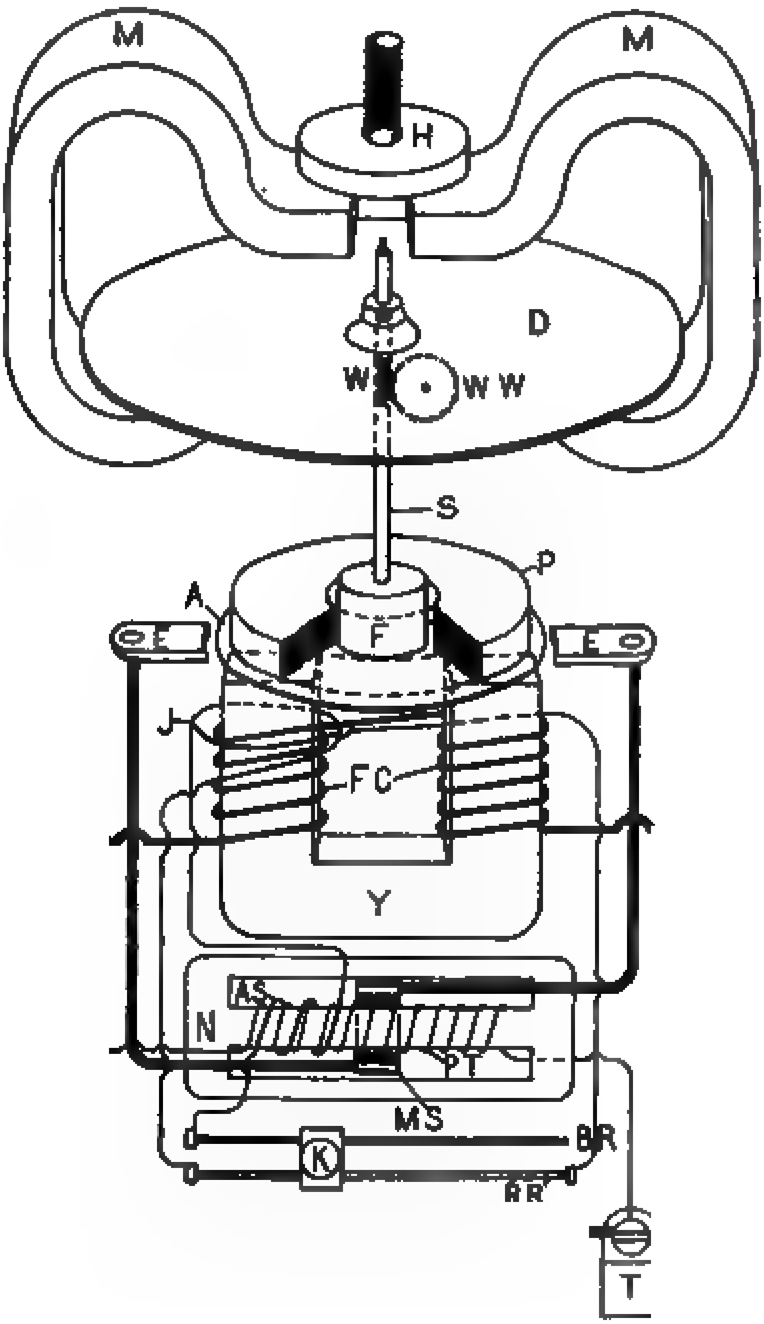


FIG. 635.—Internal Connections of Sangamo, Type P, Alternating Current Watt-hour Meter.

BR.—Small brass wire, connected to one end of auxiliary secondary AS, so as to supply current through K to RR[1].

RR[1].—Small wire of high resistance, having opposite ends con-

nected to the two branches of auxiliary secondary from J. When K stands near middle of BR and RR^1, the resistance both ways through R and R^1 to J is equal, and there is no light load compensating effect; when K is near left end, the reduction in resistance through one wire to J, and increase through the other, gives a forward or proper compensating effect; if K is near the right end, a backward rotative effect results. This arrangement thus enables absolute O of compensation to be obtained, thus preventing creeping.

In the alternating current meter the armature carries continually —while pressure is on the circuit, a current in proportion to the voltage, and the U-shaped laminated magnet is energized by series windings. As the current in the low-tension winding of the transformer and through the armature is proportional to the voltage and in phase therewith, a reaction between the armature and field is obtained proportional to the true power, and having the motion controlled by the usual damping disk and permanent magnets, a true alternating current watt-hour meter is obtained.

In the alternating current meter, light load adjustment is obtained by passing around the poles of the series laminated magnet a small volume of current derived from an auxiliary low-tension winding on the transformer, and with means provided for adjusting, from zero to a maximum necessary amount, the value of this current.

The main speed adjustment, recording trains, cover, connection box and other mechanical features are exactly the same in the Type F as in the Type D meter.

Test constants, gear ratios, and so forth, for this type of meter are given in Chapter XV.

Ampere-hour Meters

The ampere-hour meter as now made was really a reversion to the original type of mercury meter, although in the course of the Sangamo Company's business, happened to be a development from the Type D watt-hour meter.

In July, 1908, the first ampere-hour meter of this type was made for use as an indicator of the floating point of a large reserve battery. Ampere-hour meters were put on the market in the beginning of 1909.

In the ampere-hour meter the same general features have been used throughout as in the Type D watt-hour meter except that a permanent driving magnet is substituted for the potential circuit energized magnet of the Type D meter.

In the ampere-hour meter the torque is thus proportional to the constant

field of the permanent magnet and the current passing through the armature, and having the usual arrangement of damping disk and magnets the torque is proportional to current instead of power. By a recording mechanism, a record is thus obtained of ampere hours instead of watt-hours, and the operation of an ampere-hour meter is exactly the same no matter what the voltage of the circuit may be.

On account of the many uses which have developed for ampere-hour meters, the Sangamo meter has been built with various modifications of base, recording trains, and auxiliary features. For the purpose of this

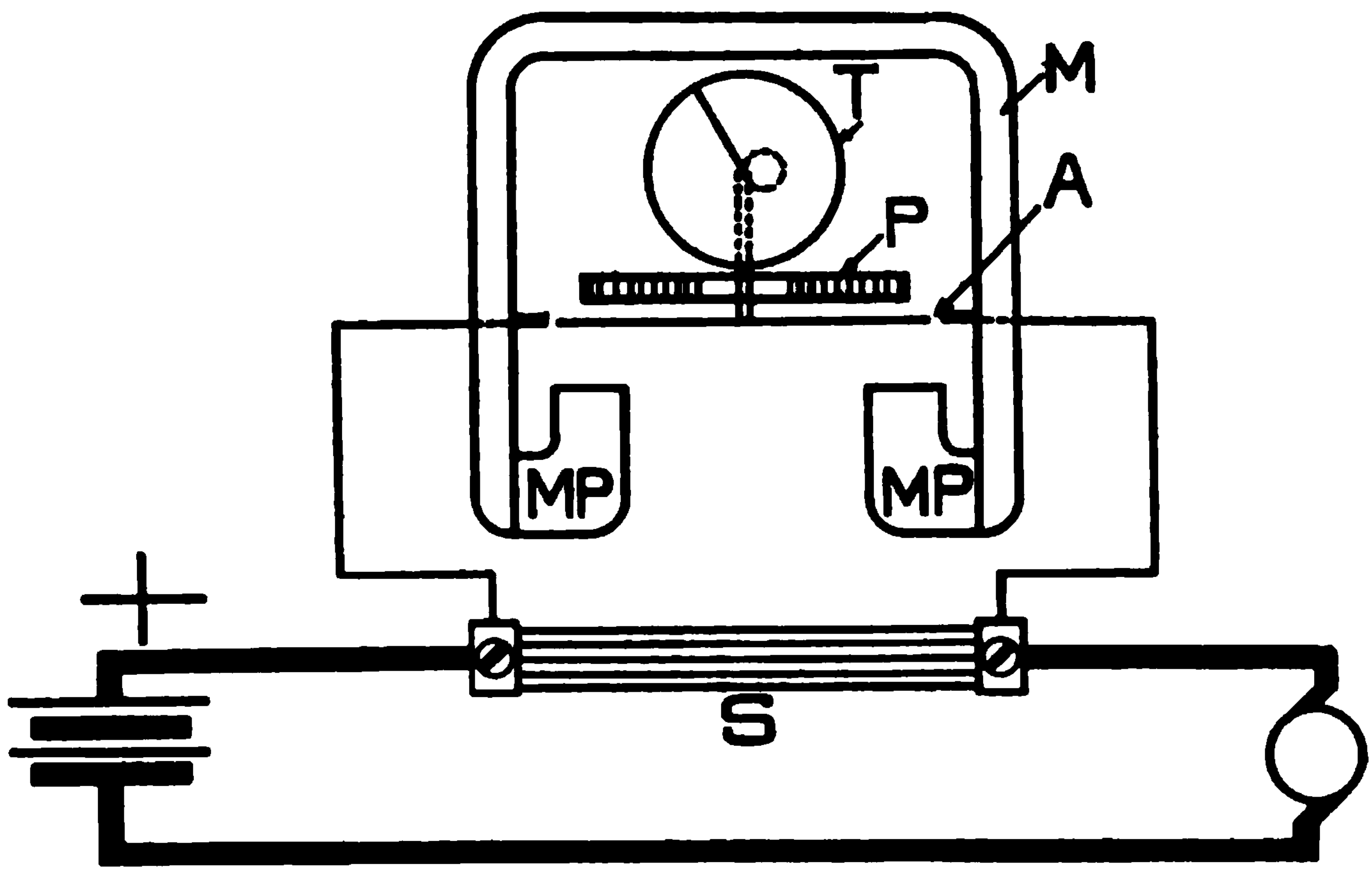


FIG. 636.—Sangamo Ampere-hour Meter with Simple Shunt.

description it may be said that the usual form of recording train on ampere-hour meters is a large circular dial, having a dial hand adapted to show by its position on the dial, the condition at any time of the storage battery to which the meter is connected.

By various combinations in the ampere-hour meter, and particularly a differential shunt adapted to make the meter run slower on charge than on discharge, a percentage of overcharge can be obtained automatically for a storage battery (Figs. 636 and 637).

The meters are used in connection with batteries on electric vehicles, on electric-lighted steam railroad cars, in street car service, with central station batteries and for control of electroplating operations. By an arrangement of contact operated by the dial hand when the battery i:

fully charged, the ampere-hour meter can be used as a relay to cut off the battery at full charge through an auxiliary shunt trip circuit breaker (Fig. 638).

Another type of recording train used on ampere-hour meters is the duplex type, having one row of four dials for charge and a second row for discharge so that the entire input and output of a battery may be recorded on the single duplex register.

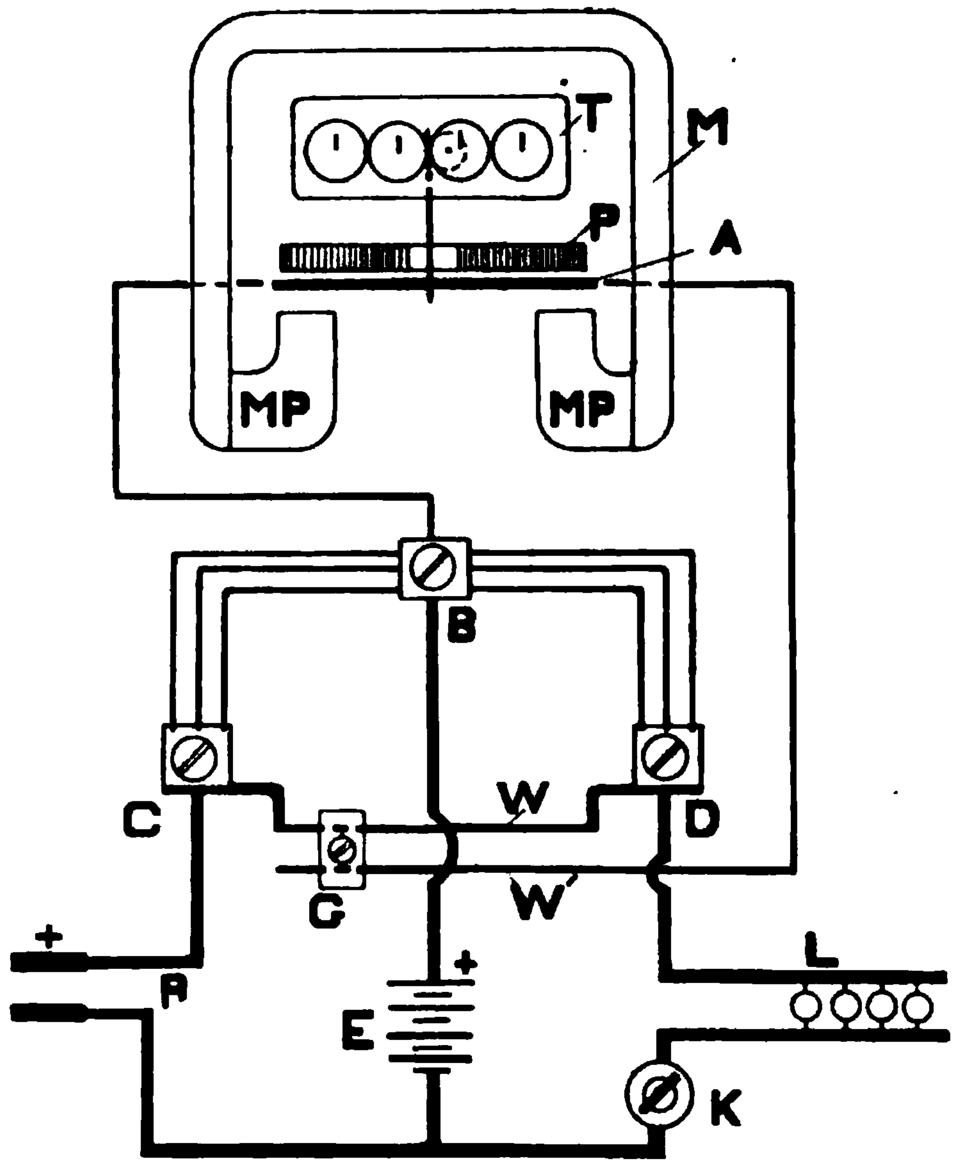


FIG. 637.—Sangamo Ampere-hour Meter with Differential Shunt.

The **electroplating ampere-hour meter** is employed to afford a more convenient and accurate record of the amount of metal deposited in a plating bath in a given elapsed time than may be obtained by noting the average current flow during the period by observing an indicating ammeter. This method also may do away with the necessity of computing the average current with the electrochemical equivalent of the metal being deposited, as the ampere-hour meter may be furnished for electroplating with a register which reads in any desired unit weight of the metal with which the meter is to be used: for example, pennyweights of

silver, grains of gold, or pounds of copper, according to the conventional methods of expressing the weights of the various precious and base metals in use by electroplaters.

In design, the electroplating meter may be similar to the watt-hour meter, but the internal arrangement differs from it, this meter being an ampere-hour meter and not a device for recording watt-hours. In actual construction, a large movable pointer operated by a knob in the middle of the glass window over the dial face is provided,

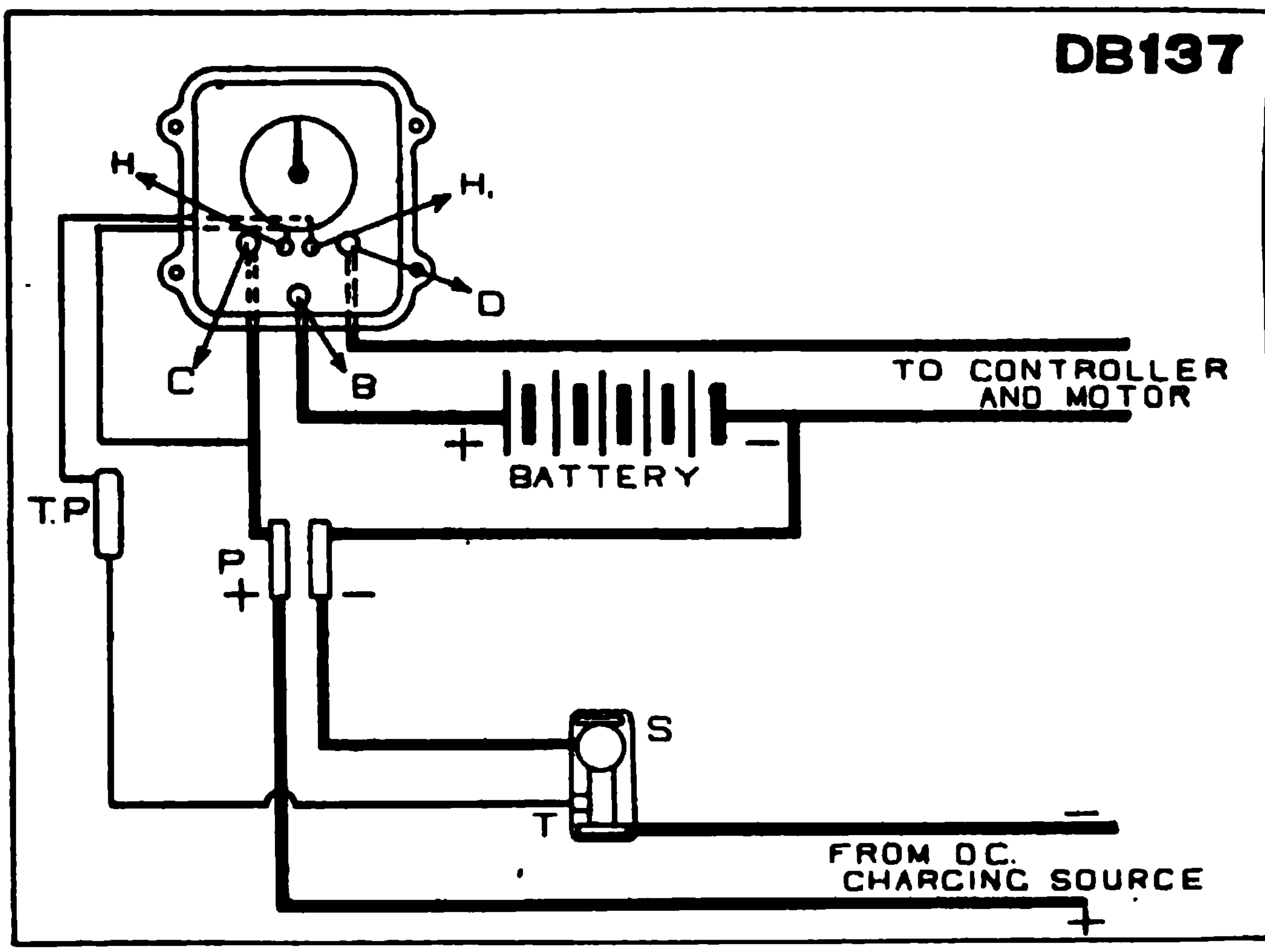


FIG. 638.—Diagram of Sangamo Ampere-hour Meter with Differential Shunt Connected on Vehicle.

to be set at the point on the dial indicating the amount of metal which it is desired to deposit in any particular plating operation—thus giving a plain reference point for the workman and facilitating the discontinuance of the plating when the ampere-hour meter dial hand reaches the predetermined figure on the scale. The meter dial hand, on reaching the hand-set pointer, makes an electrical contact therewith and operates a visual, or audible, signal to the workman; or the contact may be arranged to trip a circuit-breaker to automatically interrupt the plating current (where the leaving of the work in the plating bath is unobjectionable). The meter is capable of application in silver and nickel plating; and of value in the control of gold plating, in which, on account of

the relatively small amount of gold ordinarily deposited, requiring too small a current to be recorded with accuracy, it is advisable to employ two meters in series, a main and an auxiliary meter, the difference in the readings of the two meters giving high accuracy in work with this precious metal. The idea (shown in Fig. 639) is to have an auxiliary load of sufficient amount to give accurate registration on both meters. The main meter, connected with the gold bath, will register an amount greater than the auxiliary meter by the amount of current passing through the bath.

The ampere-hour meter has an **application to electric vehicles,** inas-

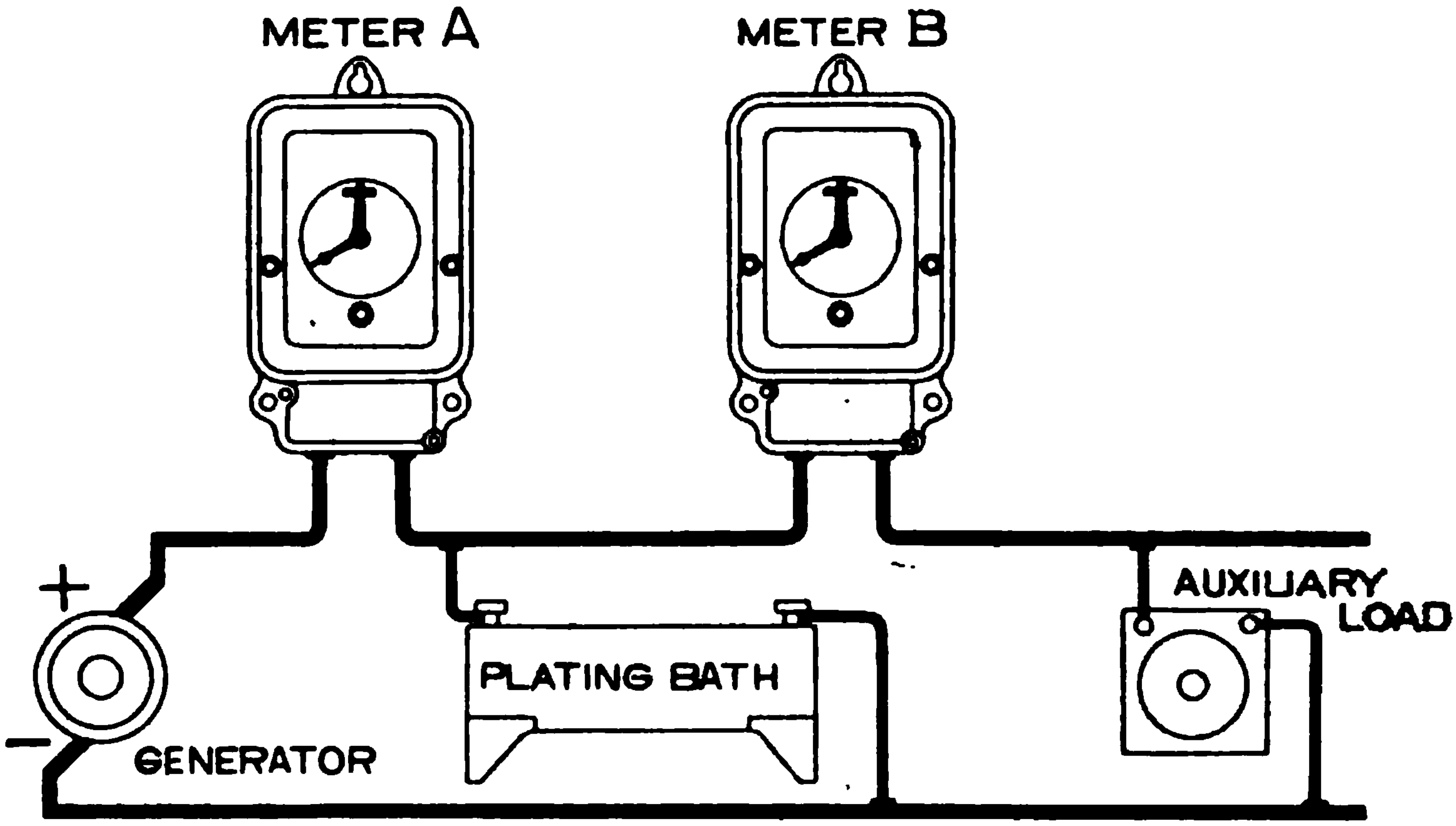


FIG. 639.—Two Sangamo Ampere-hour Meters Connected for the Measurement of Gold-plating Current.

much as it affords a direct, convenient and accurate method of determining the "miles in the battery," without noting the readings of the dashboard ammeter and voltmeter in the pleasure vehicle, or truck. Practical economy in operating electric vehicles, or electric boats, and safety to the propelling battery alike make desirable a method of determining the condition of the store of electrical energy carried by the vehicle, which will be within the intelligence or skill of the driver.

The **auto-type ampere-hour meter** affords a continuous record of the actual ampere-hours (virtually the miles) available in the vehicle battery during every trip, and it does this by integrating the energy discharge of the battery and showing the progressive lowering of total energy in

the battery by a dial hand which sweeps over a dial calibrated in ampere-hours. In charging the battery in the garage the dial hand may be moved over the scale in one direction registering the energy stored in the battery until the full charge has been put in. On starting out on a trip, the dial hand, therefore, shows the driver the total ampere-hours available in his battery; and as the vehicle travels over its route the dial hand moves backward over the scale, showing a progressively diminishing number of ampere-hours left in the battery, until the arrival of the dial hand at the zero indicates the limit of discharge of the battery. Most electric vehicle manufacturers prefer to use the meter operating the dial hand in

FIG. 640.—Sangamo Automobile Type Ampere-hour Meter.

the reverse direction from that explained above, so that, as the battery is discharged, the dial hand moves up the scale, moving back to the zero on charge. This arrangement allows the use of a contact at the zero point which may be employed to trip a circuit-breaker when the battery is fully charged (Fig. 640).

This **ampere-hour meter** is sometimes used on **electric railway systems,** to check and record the actual amount of current consumed by each car, and supplies a record of comparative current consumption, enabling electric railway managers to offer a strong incentive for the motorman to handle his car to the best advantage and with economy of current (Fig 641).

The latest development in the ampere-hour meter is the **distant oper-**

ated type in which the meter proper has a special recording train adapted to close a circuit at definite ampere-hour intervals and by this action an electrically operated mechanism is caused to move step by step. With this arrangement the register mechanism can be placed at any remote point desired from the meter (Fig. 642). By an arrangement of electromagnets in the register mechanism the motion of the dial hand on the dial is made at different speeds on charge and discharge, where

FIG. 641.—External View of Sangamo, Street-car Type, Ampere-hour Meter.

it is desired to obtain the automatic overcharge as above referred to (Fig. 643).

Further discussion of measurement of electrical energy by means of ampere-hour meters will be found in Chapter IV, and a discussion of some other types in Chapter III.

The test constants and various ratios are discussed in Chapter XV.

SANGAMO INDUCTION TYPE WATT-HOUR METERS

The early Sangamo watt-hour meters were designed on the usual induction motor principles explained in Chapter III, and consisted,

therefore, of an induction motor element, operated by a rotating magnetic field interacting with induced currents in a closed circuited rotor; a generator element to provide load and braking affect for the motor element, and a revolution recording mechanism. These were combined, in general, in a manner to produce a commercial electricity

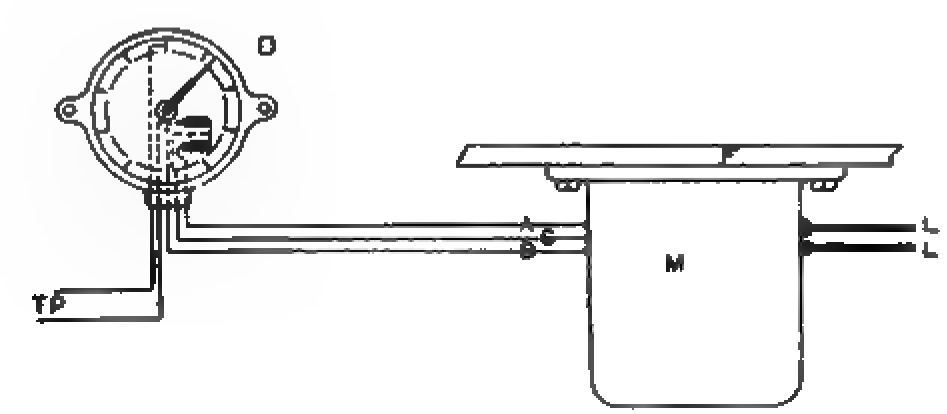


Fig. 642.—Remote Control Type of Ampere-hour Meter Register

meter of what is known as the induction motor type. The earlier types were known as the Gutmann meters.

Description of Various Types

Gutmann Meters (Type A)

The original Gutmann induction watt-hour meter was developed in 1898 and put on the market in the spring of 1899. In this meter

Fig. 643.—External View of Sangamo, of Switchboard Type, Ampere-hour Meter.

the rotor was an aluminum cylinder, slotted in spiral lines, and with damping disk riveted on the lower end of the cylinder. The cylinder was acted upon by a U shaped potential circuit magnet and a pair of open series coils without iron cores, held on a supporting bracket by

porcelain spools. Heavy load adjustment in this meter was obtained by moving the permanent magnet in and out on the damping disk and light load adjustment by moving a crescent shaped laminated iron core within the cylinder, this being a continuation of the potential circuit magnet outside the cylinder. The Type A Gutmann watt-hour meter was not provided with any compensation for inductive load; that is, the potential circuit magnet was not lagged. As this meter was only made for a short time, and was superseded by the Type B, or disk type, no attempt has been made to give a description in detail of its construction or to give data on it.

Type B

The disk type of Gutmann meter was a development from the earlier cylinder type. In the Type B the rotor consisted of an aluminum disk with spiral slots arranged so as to give a torque effect between the potential circuit and series fields, which were placed with their effective centers in a radial line so that no torque was exerted on an ordinary blank, or unslotted, disk. The potential circuit magnet consisted of two sets of laminations bolted together so as to form a single air gap, the magnet being energized by a coil on the rear arm of the upper, or main portion. The series coils were carried on an aluminum bracket between the gap of the potential circuit magnet and the center of the disk; one coil above, and one below the disk, each coil having within it a small bundle of laminated iron, not having, however, any complete or return magnetic circuit for the lines of force between the two coils.

The damping magnet was placed on the opposite side of the center from the driving element and adjustment for main speed was obtained by swinging the damping magnet in or out from the center of the disk toward the edge, in the usual manner. Light load adjustment was obtained by means of a soft iron vane attached to the inner side of the potential circuit magnet, and with a foot at the lower end adapted to act upon the disk in conjunction with the main potential circuit field. The iron strip was surrounded by a short-circuited conductor so as to have a considerable difference in phase in the flux from the foot of the vane and the main potential circuit field. By raising and lowering this vane, or by swinging it backward and forward, a light load adjustment was obtained.

Compensation for inductive load was obtained by a heavy band of copper placed around the lower arm of the potential circuit magnet, the band being left open on the lower side and arranged with a copper, or iron, loop which could be moved in and out of blocks on the

band to vary the resistance of the short-circuited secondary composed of the band and loop. By moving this loop an adjustment was obtained for low power-factors.

The recording train of this watt-hour meter was of the five dial type, reading in watt-hours, and was driven from the shaft of the meter through a worm and worm wheel.

The bearing was a cup sapphire jewel held in a setting above a light spring, and the lower pivot was polished directly on the disk shaft so that it was necessary to either repolish, or replace, a shaft in case of a pivot proving defective.

This type of watt-hour meter was made with both cast aluminum and glass cases, and was manufactured in considerable quantities until November, 1903. The manufacture of the Gutmann watt-hour meter was discontinued at that time in the United States, owing to patent litigation, but was continued about three years longer in Canada.

Data on the Type B Gutmann meter is given on tables herewith:

Full load speed—50 rev. per min.

Torque at full load of 500 watts (5 amp. 110 v.)—16 mm-g.

Weight of moving element—25 g.

Ratio of torque to weight—0.64.

Volts drop in series coil at full load (5 amp.)—0.40 and less in larger capacities.

Watts lost in series coil at full load—1.0 approx.

Loss in potential circuit—110 volts, 60 cycles, 1.5 watts.

Power-factor of potential circuit—at 60 cycles about 0.40.

Date of original production—October, 1901.

Testing formulas:

W = Watts load
R = Disk revolutions
S = Time in seconds, for one revolution
T = Train ratio

$$K = \text{Watt-seconds per revolution of disk for meter under test} = \frac{3{,}600}{T}$$

Since, $$S = \frac{KR}{W}, \text{ or}$$

$$R = \frac{WS}{K}, \text{ and}$$

S^1 = observed time for $\frac{1}{10}$ revolution

$$\text{Then} \qquad E = \frac{S^1 - S}{S}$$

Test constants, gear ratios, and so forth, for this type of meter are given in Chapter XV.

The size of holes in binding posts for this type of meter of capacities of 5, 10 and 15 amperes, is $\frac{5}{32}$ inches; 25, 50, 75 and 100 amperes is ¼ inches, and for larger capacities cable lugs are used.

This type of meter was put on the market in the fall of 1901.

Type H

The Type H single-phase induction watt-hour meter consists essentially, like all other induction meters, of a light aluminum disk armature subjected to the action of potential circuit and series fields, the speed being controlled by permanent damping magnets in the usual manner and transmitting the motion to a four dial recording train through a worm and wheel drive direct from the shaft. The field arrangement of this meter differs somewhat from former induction meters, but resembles in some respects the arrangement of the Gutmann induction meter built by this Company some nine or ten years ago. That is to say, the Type H embodies essentially a potential circuit magnet entirely independent of the series magnetic structure, which was also characteristic of the Gutmann meters, but in other respects, such as the construction of the moving system, torque, etc., is very different from the Gutmann meter.

On account of the field arrangement, all parts except the potential circuit magnet are carried on a cast iron grid. This is shown in Fig. 644. The laminated crescent shaped plate forming the return path for the series magnetic field is held above the armature and does not have to be removed in repairing a meter.

The moving element consists of an aluminum disk 3½ inches in diameter with a weight of 15.4 grams, although the first meters of this type had a disk weighing about 18.6 grams. The disk is carried on a brass shaft with removable double ended lower pivot and a worm is cut on the upper end of the shaft above the disk—driving directly through a worm wheel and shaft to the recording train. The upper bearing is designed so as to give a slight flexibility to the shaft to prevent rattling.

The lower bearing as first supplied with these watt-hour meters consisted of a ring jewel and flat jewel, but it was found that this type

of bearing had a tendency to cause rattling, particularly in low frequency meters, so that there is now furnished a cupped sapphire

Fig. 644.—Sangamo, Type H, Single-phase, Induction Watt-hour Meter

lower jewel bearing mounted fixed in the lower bearing post and with a sleeve above it which prevents the shaft dropping out of posi-

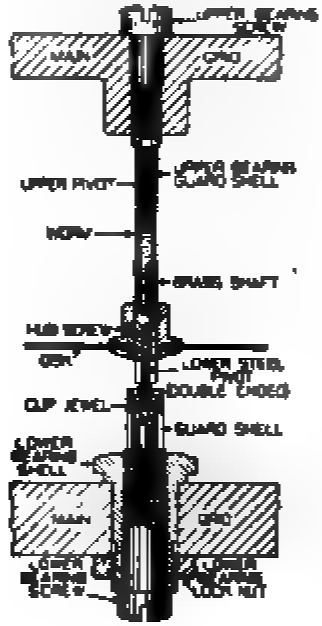


Fig. 645.—Bearings of the Sangamo, Type H, Induction Watt-hour Meter

tion during shipment, or when the meter is handled. The two types of lower bearing are made with bearing screws exactly interchangeable so that either one may be substituted for the other (Fig. 645).

The meter has two adjustments as shown in Fig. 644, the main speed, or full load, adjustment being obtained by a soft iron disk mounted on a vertical screw so that it can be moved relatively to the lower jaws of the two permanent magnets. This is the same arrangement which has been used for a number of years in Sangamo mercury motor meters. A range of about 25% in speed is obtained by this adjustment.

The light load adjustment consists of a copper vane carried on a brass lever which projects down in front, on each side, of the portion of the grid carrying the lower bearing and full load adjustment. The vane stands in the gap of the potential circuit magnet beneath the disk, and by moving the lever at the front a slight distortion of the potential circuit field is caused, thus giving an adjustment on light load either backward or forward.

Creeping is prevented by two small holes punched in the aluminum disk on the same principle as the slots used in the disk of the Type B Gutmann meter. No adjustment is provided for inductive load compensation as a winding on the tip of the potential circuit magnet just below the potential coil is provided and adjusted at the factory to give approximately correct compensation at 50% power-factor. If desired to have very close compensation at low power-factor, the terminals of this winding can be disconnected and a small amount of resistance inserted so as to bring the potential circuit field in exact quadrature with the impressed e. m. f.

The Type H watt-hour meter is so designed as to be shielded from severe short circuits or external magnetic fields, and the series coils are designed to have a continuous overload capacity of 100%.

The torque in the first Type H watt-hour meters, having a heavier moving system, was 50 millimeter-grams at 110 volts, 60 cycle. In the meter as now furnished the torque is slightly over 40 millimeter-grams giving a ratio of torque to weight of about 2.8.

The meter is supplied in all capacities from 5 to 100 amperes inclusive, 2-wire and 3-wire, without current transformers, and from 150 amperes upward with current transformers in the usual way.

The meter has a four dial porcelain dial face, reading direct in kilowatt-hours for all capacities and is furnished either with pressed glass, or pressed aluminum, case; black finish (Fig. 646).

The connection box is similar to that used on former Sangamo watt-hour meters, being below the meter and the cover arranged to swing down at one corner so that it may be sealed at the other corner when closed.

The Type H watt-hour meter is 5¾ inches in diameter, over the

base, and 7¾ inches long from top of hanging lug to bottom of connecting box.

Size of holes in binding posts for this type of meter is, for 5 to 20 amperes capacity inclusive and all sizes with current transformers, 0.166 inches; for 30 to 100 amperes capacity inclusive, 0.27 inches.

FIG. 646.—Sangamo, Type H, Induction Watt-hour Meter Dial Face, Canadian Pattern The Standard Dial Face is Similar, except that Test Dial is Eliminated.

The following is data on performance of Type H watt-hour meters:

Full load speed—40 rev. per min.

Torque at full load of 550 watts (5 ampere, 110 volt meter)—40 mm-g.

Weight of moving element—15.6 g.

Ratio of torque to weight—2.5 approximately.

Volts drop in series coils at full load—Less than $\frac{1}{10}$ volt.

Watts lost in series coil at full load—Less than ¼ watt, 5 ampere-meter.

Loss in potential circuit—1.6 watts for 110 volts, 60 cycles, and 1.85 watts for 220 volts, 60 cycles, 2½ watts at 110 volts, 25 cycles.

Power-factor potential circuit—approximately .35.

Testing formulas—K = watt—seconds per revolution of disk.

W = load in watts.
S = correct time for one revolutions in seconds.

$$\text{Then} \quad S = \frac{K}{W} \text{ or}$$

$$WS = K$$

The test constants, gear ratios, and so forth, for this type of meter are given in Chapter XV.

This type of meter was produced in March, 1911.

Fig. 647 shows the Sangamo rotating standard and connections for use.

Conditions Causing Meters To Run Fast or Slow

Gutmann Meter, Type B

The principal cause of running fast in these watt-hour meters was weakening of the permanent magnets.

The principal cause of running slow in Type B watt-hour meters was jewel and recording train trouble. Jewel trouble from wear in the ordinary way, and recording train trouble principally through gumming up, as oil was used on the bearings in these trains, a practice which was afterwards abandoned.

Type D

The Type D watt-hour meter has occasionally run fast on light load, or has crept, due to grounding out of some of the resistance in the circuit of the thermo couple to the armature, in types where the thermo couple is used. The principal troubles in Type D watt-hour meters have been running slow both on light load and heavy load. Running slow on heavy load has in some cases been due to the partial grounding out of turns in the potential coils, thus reducing the potential circuit field strength; and in the case of shunted meters, from an increase in the resistance of the by pass circuit through the meter, as compared with the shunt.

On light load the principal troubles have been either in the middle ring jewel bearing, or in the lower bearing. There has been very little actual jewel trouble in the sense of jewel wear, owing to the flotation of the moving system in these meters, but considerable trouble was experienced through collection of dross around the ring jewel in the cover of the mercury chamber, thus collecting between the jewel and spindle and causing a considerable drag on light load. This trouble has been largely eliminated in present meters by the use of a steel tube which extends around the spindle into the mercury. Some trouble has been experienced with the lower, or guide ring, bearing in the bottom of the mercury chamber due to rusting, or gumming up, and in the meter as now made, this has been largely overcome by the substitution of a ring jewel, like that used in the cover of the mercury chamber.

Some trouble has also been found in the earlier meters through change in alignment of the motor element with respect to the upper

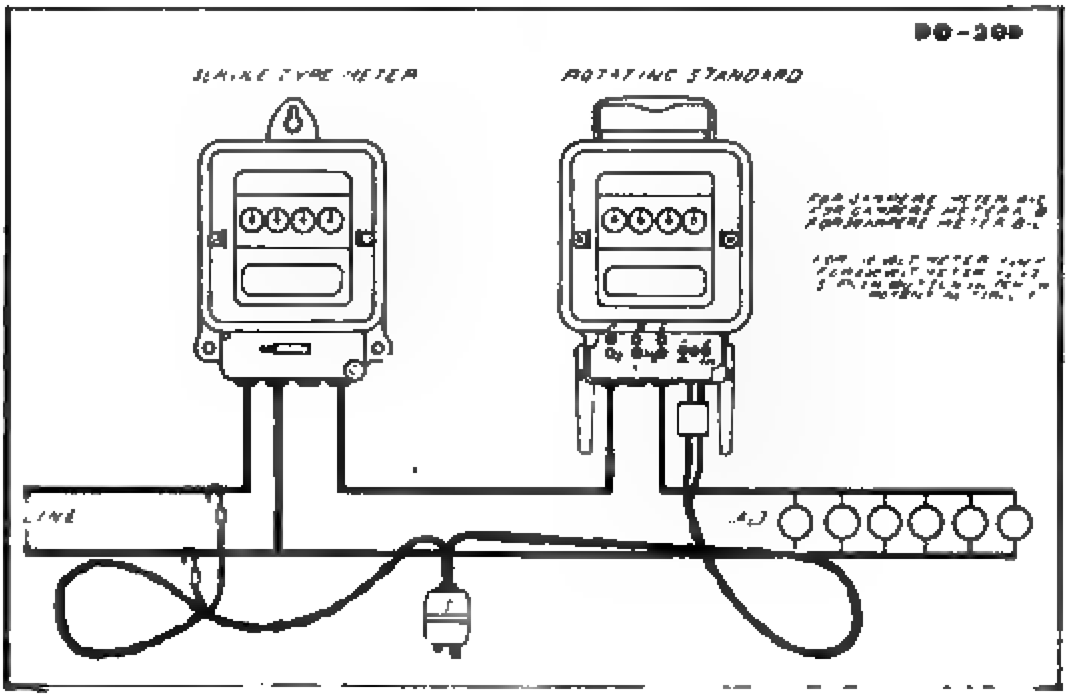


Fig. 647.—Sangamo, Alternating Current Standard and Diagram of Connections for Use

bearing for the shaft of the damping disk—and this has been rectified in later meters by rigidly doweling and fastening all such parts

In some cases continuous current meters have run slow on light load due to a breaking of the thermo couple compensating circuit: that is, the element of the thermo couple supplying current at low potential to the armature, and in such cases it is necessary to remove the thermo couple and substitute a new one.

Type F

As the Type F watt-hour meter is practically the same in construction as the Type D, the same troubles as stated have been found in it, and also some trouble due to change in resistance of contact between the terminal ears of the mercury chamber and low-tension leads from the internal transformer. This trouble has been corrected by nickel plating the low-tension leads as well as the contact ears.

Ampere-Hour Meters

Ampere-hour meters are subject to the same general statements as given under Type D, and Type F except that in the ampere-hour meter there are no windings of any kind to change characteristics and thus change the speed of the meter.

On the other hand, in the ampere-hour meter the large permanent driving magnet is subject to a possible decrease in strength through age, or vibration, in service, and if this happens a meter will have a tendency to run slow.

In the ampere-hour meter the tendency to run slow on light load is always more pronounced owing to the fact that there is no initial light load compensation.

Type H

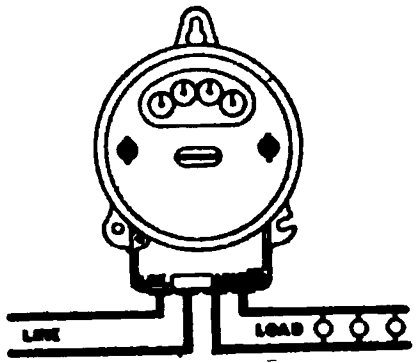
Causes which would make a Type H watt-hour meter run fast on full load are the weakening of the permanent magnet or cutting out of some of the turns in the potential coil. As the potential coil is made on the Acme system, it is thoroughly insulated between every turn and every layer.

On light load, creeping may occur, due to over-compensation initially, or to a change in the position of the light load adjusting vane through vibration and on account of not being set down tight when adjusted.

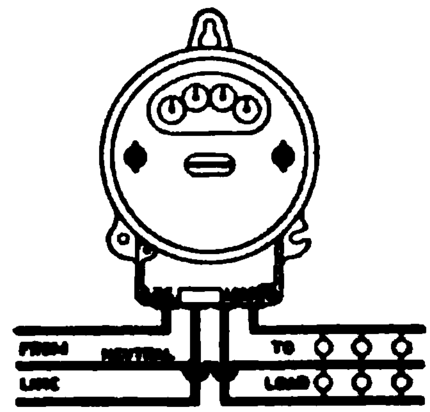
Type, H watt-hour meters could also run slow on light load due to change in the position of the light load adjustment in the same way as stated above for a possible tendency to run fast.

External connections for these types of meters are given in Fig. 648 and external dimensions in Fig. 649.

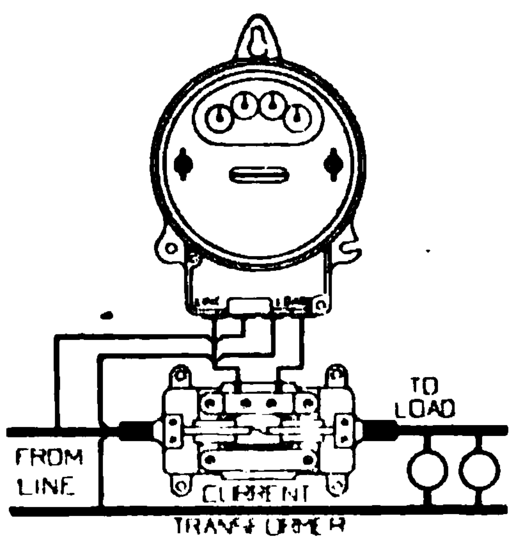
External Connection Diagrams



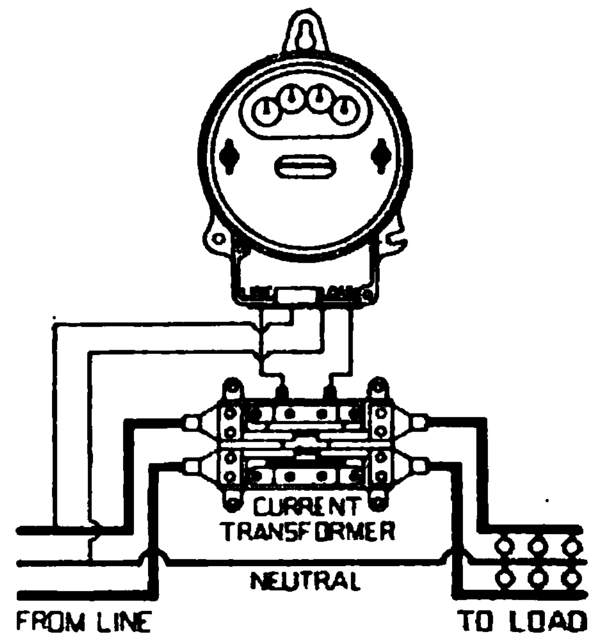
2-wire, 5–10 Amperes.



3-wire, 5–10 Amperes.



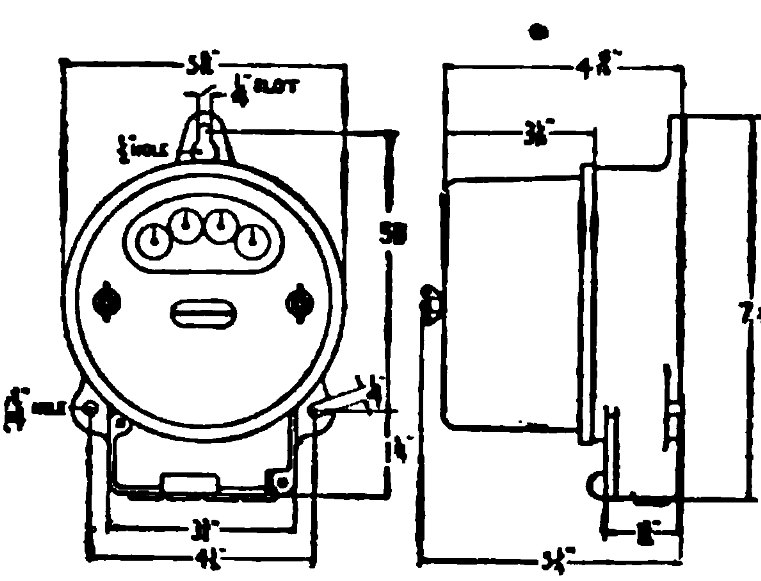
2-wire, exceeding 100 Amperes.



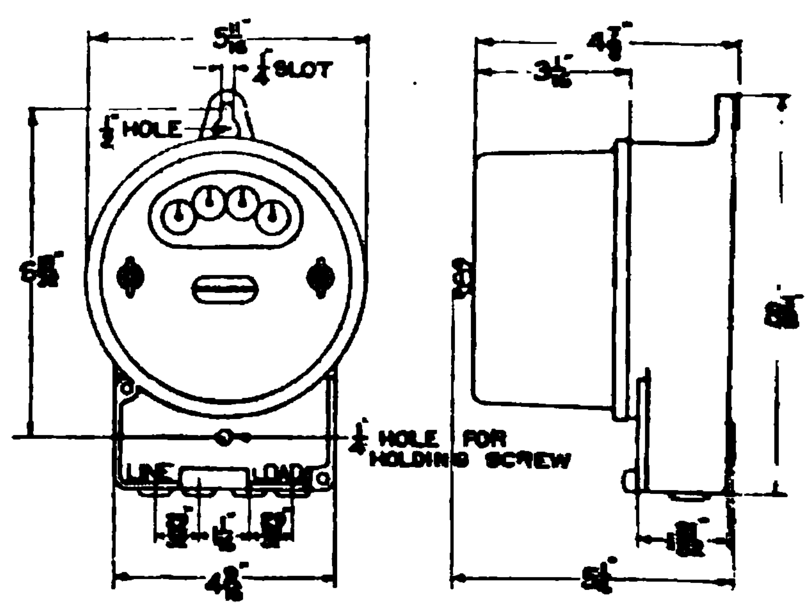
3-wire, exceeding 100 Amperes.

FIG. 648.—External Connections for Sangamo, Type H, Induction Watt-hour Meters.

External Dimension Diagrams



2- and 3-wire, 5-20 Amperes Self-contained; also exceeding 100 Amperes when Using Current Transformers.



2- and 3-wire, 30-100 Amperes Self-contained.

FIG. 649.—External Dimensions of Sangamo; Type H, Induction Watt-hour Meter.

DUNCAN CONTINUOUS CURRENT WATT-HOUR METERS

The Duncan continuous current energy, motor meters depend upon the principle of the well-known electrodynamometer for their operation, in which the electromagnetic action between the currents in the field coils and a revolutable armature produces motion in the latter. It also embodies the other two necessary watt-hour meter elements required for the speed control and registration of the revolutions of the armature, these being embodied in the drag magnet and disk and the meter register, respectively. The motion of the armature is converted into continuous rotation by the aid of a commutator and brushes—the commutator being connected to the armature coils and carried on the same spindle therewith. In general, the description of commutator type of meters given in Chapter III will apply to these meters (Fig. 650).

Description of Various Models

Model A

The Duncan Model A watt-hour meter (Fig. 651) is a general name employed to designate the house type watt-hour meters manufactured by this company previous to the summer of 1908. The serial numbers on these watt-hour meters are less than 76,000 and they are distinguished from later types by the fact that their registers have five dials.

This meter has two field coils situated on opposite sides of an armature, the latter being carried by a shaft which also carries an aluminum braking disk and a commutator. The majority of these watt-hour meters have light load compensating coils of 1,000 turns each, wound in ten sections with taps brought out to a multipoint switch so arranged that the number of turns in the potential circuit can be increased or decreased by shifting the switch arm, thus varying the starting torque for light load compensation.

The armature consists of eight coils, each coil having 1,000 turns of No. 40 B. & S. gauge single silk covered wire. The commutators have eight segments each.

The base of this meter is an aluminum casting. The arch and shelf are brass castings. The cover is made of sheet zinc and provided with a window over the dial face only.

This type of watt-hour meter is equipped with a threadless jewel post, held in place by a wire retaining spring, which engages the

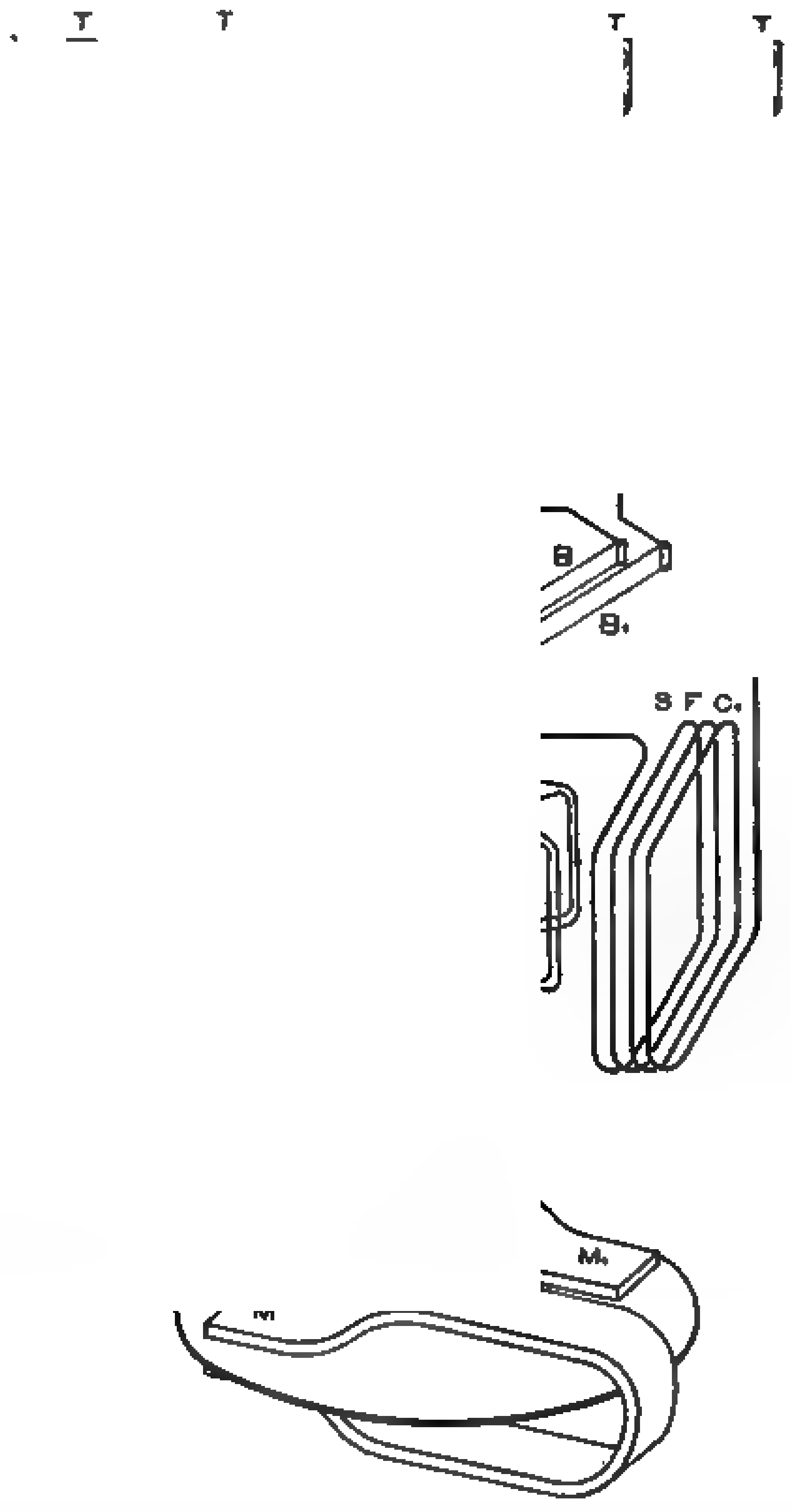


FIG 650.—Internal Connections of Duncan, Model B, Continuous Current Watt-hour Meter *A*, armature, *BB*, bus-bar, BB_1, brushes; *C*, commutator; *CC*, friction compensating coil, *D*, disk; MM_1, drag magnets, *R*, resistance, *S*, shaft; *SFC* and SFC_1, series field coils; *Sw*, switch for compensating coil; *T*, terminals; *W*, worm on shaft; *WW*, worm-wheel of register.

bottom or side of the post, according to whether the jewel is in place or is lowered for transportation.

A cupped, step, or jewel bearing, made from Australian sapphire, is used, except in the larger sizes of watt-hour meters, that is, above 600 amperes in house type, and over 1,000 amperes in switchboard type, where a cupped, diamond jewel is used.

The spindle point, or that portion of the shaft which rests upon the sapphire cup, is detachable and is held in position at the bottom of the spindle by magnetism. A type of step bearing is used in these

FIG. 651—Duncan, Model A, Continuous Current Watt-hour Meter

meters which permits of a visual inspection of the jewel and pivot while the meter is in operation (Figs. 652 and 653).

This model was produced in 1902 and the serial numbers ran to 76,000.

Model E

The Duncan Model E watt-hour meter (Fig. 654) is a development of Model A, retaining practically the same electrical characteristics but differing considerably from the old type in mechanical construction. In this meter all metal parts including base, arch, shelf and cover, are formed up from heavy sheet metal, on punch presses by means of dies. This watt-hour is further improved by the use of tubular spindle, wire brushes and $\frac{4}{16}$ inch diameter commutator.

The armature winding is the same as in Model A, but the light load compensating coil has but 400 turns, divided up into ten sections. On account of lighter moving element and reduced friction, it has

been possible to reduce the starting torque, or light load compensation, 60% below that in the Model A.

The cover is made out of sheet metal with glass windows over the dial face and over the disk. A special type is furnished at an additional cost having an all glass front.

FIG. 652.—Sectional View of Visual Bearing and Threadless Jewel-post

FIG. 653.—Visual Bearing Open (Front View).

1. Spindle.
2. Hub of aluminum disk.
3. Ring for clamping split extension of hub to spindle.
4. Set screw for clamping ring.
5. Aluminum retarding disk.
6. Detachable spindle point.
7. Top of support for collar and jewel bearing.
8. Visual bearing collar.
9. Oriental sapphire jewel bearing.
10. Jewel stud.
11. Jewel spring.
12. Jewel post.
13. Meter base.
14. Wire retaining spring.

a. Split extension of hub.
b. Stop to rest on 7 when jewel post is lowered.
c. Lower and tapered portion of spindle.
d. Jewel post shipping groove.
e. Jewel post service groove.

These meters are made in sizes from 2½ to 600 amperes inclusive for 110, 220 or 550 volts, 2-wire and 220 or 550 volts, 3-wire.

This model was produced between June, 1908, and March, 1912, and includes serial numbers from 76,000 to 150,000; from March, 1912, to present date this model has been manufactured in serial numbers above 150,000.

Model E meters having serial numbers larger than 150,000 are the same in electrical and mechanical design as those having serial num-

Fig. 654.—Duncan, Model E, Continuous Current Watt-hour Meter

bers from 76,000 to 150,000, excepting the former are provided with a new system of registering trains and a new type of plain dials bearing the words "kilowatt-hours" only.

Model EA

The Duncan Model EA watt-hour meter (Fig 655) is similar in construction to the Model E in all details excepting that the

Fig. 655.—Internal View of Duncan, Model EA, Astatic Continuous Current Watt-hour Meter

armature and field coils are arranged astatically. This combination is secured by connecting the coils so as to give a four pole field and by using a wave wound armature having 17 coils.

In all particulars excepting the armature and field construction, this meter corresponds and is similar to the Model E.

The test constants, ratios and testing formulas for this type of meter are given in Chapter XV.

This model was produced in January, 1912.

Model R

The Duncan Model R switchboard watt-hour meter (Fig. 656) is a shunted type of watt-hour meter very similar in principles of operation to the Model E, house type meter. The meter has four

FIG. 656.—External View of Duncan, Model R, Switchboard, Continuous Current Watt-hour Meter.

field coils so connected as to set up a four pole astatic field. Two field coils are connected in series and each pair of field coils requires 20 amperes on full load, at which current, the drop is 80 millivolts across the shunt. On a two-wire watt-hour meter, 40 amperes is taken from the shunt, 20 amperes for each pair of field coils, while three-wire meters are provided with two shunts from each of which is taken 20 amperes.

The armature is purposely made large in diameter, light in weight

and is so connected as to develop a four pole astatic field. This combination of field coils and armatures gives an astatic combination.

This type is furnished with an all glass cover and the interior parts are polished, enameled, plated or otherwise finished to order for switchboard mounting.

Each meter is furnished with five foot leads but may be provided with longer leads if desired.

The meter is provided with a gold commutator cupped diamond, jewel bearing, multipoint compensating switch for light load adjustment and cast aluminum back support.

A diagram of connections is shown in Fig. 661.

The test constants, ratios and testing formulas are given in Chapter XV and are the same as those used with the Duncan Model E watt-hour meters.

These meters are made in sizes from 100 amperes to 20,000 amperes, although larger sizes can be furnished if desired.

This model was produced in September, 1911.

Model ER

The Duncan Model ER watt-hour meter consists of Model R mechanism assembled on the Model E base and is built with front connections. This meter is very similar to the Model FR, excepting the Model ER is front connected while the Model FR is back connected.

This type is built in sizes from 800 to 5,000 amperes inclusive.

Test constants for this type are the same as for Model R.

This type was produced in January, 1912.

Model C

This watt-hour meter (Fig. 657) is a series type of switchboard meter and is built in all sizes from 100 to 6,000 amperes, two-wire, 110, 220 or 550 volts, and 100 to 3,000 amperes, three-wire, 220 or 550 volts. In sizes from 100 to 600 amperes inclusive the coils are wound of strip copper. In sizes from 800 amperes up the coils are made up of copper castings. The series fields in all types are arranged to give four poles and a wave wound four pole armature is used so as to render the meter astatic. The armature consists of 17 coils and is connected to a 17 segment commutator. This meter is given special finishes so as to adapt it for use on switchboards. It has an all glass cover.

The test constants for these meters are the same as those given for Model E meters.

The series coil data for 100 to 600 ampere sizes inclusive is the same as for Model E.

This model was produced in May, 1909.

Model F

The Duncan Model F watt-hour meters is similar to the Model C described above in electrical design and in the mechanical con-

FIG. 657.—External Views of Duncan, Model C, Switchboard, Continuous Current Watt-hour Meter.

struction of the mechanism but differs from the Model C in having a sheet metal cover with a glass front. This type is made in sizes from 25 to 600 amperes, 110, 220 or 550 volts, two-wire and 15 to 600 amperes inclusive, 220 or 550 volts, three-wire.

Test constants, series coil data, etc., are the same as for Model C

This model was produced in June, 1909.

Model FR

The Duncan Model FR watt-hour meter consists of the Model R mechanism assembled on a Model F base with a sheet metal cover having an all glass panel front. This meter is built in sizes from 800 to 20,000

amperes and replaces the series type Model F switchboard meter in the larger sizes, since the Model F is built in sizes up to 600 amperes only.

The connections, dimensions of shunts and test constants are the same as for the Model R.

This model was produced in February, 1912.

Model G

The Duncan Model G watt-hour meter is a mercury type meter and is built specially for street car, or vehicle, work. The main field is set up through an iron core containing air gaps in which is located the armature, the core being energized by current taken from across the line so that the value of this field is a measure of the voltage of the line. The armature consists of a partially amalgamated copper disk immersed in mercury contained in a chamber made of molded insulating materials. The series current is led into the mercury chamber through copper conductors terminating inside the mercury chamber at one end and in an outside connection at the other. The load current passes into the mercury receptacle on the right hand side through the mercury into the armature disk, thence across the armature disk to the opposite side and out to the load circuit. The value of the armature field is thus proportionate to the load current thereby making the apparatus a watt-hour meter.

The series current is passed around several turns of heavy conductor wound on the outside of the potential circuit coils, thus giving a series motor effect and giving a straight line calibration curve for all loads within the meter's range. The molded insulation chamber is provided with a number of contacts projecting down from the top far enough to make contact with the mercury. These contacts are connected to a small switch having ten points. The potential circuit currents pass into the mercury chamber with the load current and out on one of the above contacts depending on the position of the switch arm. This gives an additional series motor effect of small magnitude and a starting torque to overcome friction. A feature of this instrument is a separate chamber connected to the main mercury receptacle by a channel which may be closed, or opened, by means of a valve. This auxiliary receptacle is just large enough to hold all the mercury used in the meter, and during shipment the mercury is retained in this receptacle to prevent the formation of oxide due to agitation, or churning, caused by handling.

These meters are built in sizes up to 10 amperes, self containe

above which sizes shunts are furnished. A uniform drop of 80 milli-volts at full load is used on all shunts.

This model was produced in August, 1910.

Model H

The Duncan Model H rotating standard (Fig. 658) is built in two sizes, one having a capacity of 1, 2, 5, 10, 25 and 50 amperes the other a capacity of 5, 10, 25, 50 and 100 amperes. Both of these

FIG. 658.—Duncan, Model H, Continuous Current, Rotating Standard.

types are furnished with potential coils for 110, 220 or 550 volts, or any combinations of two or more of the above voltages in one meter This meter is similar in general construction to the standard Model E house type watt-hour meter The series coils are wound in a number of sections, the terminals being brought out and connected to two systems of phosphor-bronze brushes which make contact with a controlling roller. This controller is built up of copper blocks with insulation and is so constructed that when turned to different angular positions, the different sections of the series coils are connected in

series, or parallel, or series-parallel, giving the different ampere capacities. When the controller is set for the smallest capacity, all sections are in parallel, etc. The drum controller is actuated by a handle extending to the top of the meter. To this handle is attached a pointer traveling over a dial on which are stamped the different ampere capacities. The correct position of the controller is indicated when the pointer is over the number representing the ampere capacity desired. This construction is such that there is a uniform field acting on the armature at all times and for all capacities, since all portions of the series coils are equally loaded no matter which capacity the meter may be set for.

A clamping device is provided which lifts the moving element off of the jewel for transportation.

A dial face is provided at the top, having one large dial four inches in diameter and two smaller dials. One revolution of the large dial hand represents one revolution of the meter disk and the other dials represent 10 and 100 revolutions respectively. A cam is mounted on each shaft, carrying the dial hands which is actuated by a system of levers operated by a push button on the front of the dial face. This device enables the operator to set the dial hands back to zero following each test.

The meter is started and stopped by the closing and opening of a snap switch in the potential circuit.

The outfit is assembled in a polished oak carrying case with an instruction sheet in the lid, giving diagram of connections, test constants and method of working up results. An external resistance is furnished for 550 volts.

This model was produced in May, 1909.

Model HA

Duncan Model HA rotating standard has field coils and armature connected and assembled so as to develop a four-pole astatic combination. This type of rotating standard is provided with two systems of series field coils, one of which is used for the smallest capacity and the other is used for the three larger capacities. For the larger capacities the series parallel combinations of the series fields are made by the use of plug connections and a terminal block. This meter has a zero returning device similar to the Model H rotating standard and has a clamping device for protecting the jewel during transportation.

This meter is made in 2½, 5, 10 and 25 ampere capacities, with

potential circuit coils of 110, 220 or 550 volts, or with any combinations of two or more of these voltages.

This model was produced in March, 1912.

Model H2

This model is similar in general details to the Model HA rotating standard excepting that it does not have the zero returning device and does not have the astatic arrangement of the field coils and armature. In all other particulars, it is the same as the Model HA rotating standard.

This model was produced in March, 1912.

The following is additional data pertaining to some continuous current types of Duncan watt-hour meters which has not been heretofore enumerated.

Type	Torque (mm-g.)	Weight Element (grams)	Full Load Speed (rev. per min.)	Ratio Torque to Weight on	Shunt Loss 110 V. (Watts)
Model A	180–400	180–200	36.7	1.0 –2.0	5
Model E	180–400	130–135	36.7	1.39–2.95	5
Model EA	170–360	175–180	36.7	0.97–2.00	5.5
Model R	180	106	36.7	1.70	10
Model F	170–360	175–180	36.7	0.97–2.00	5.5
Model FR	180	106	36.7	1.70	10
Model ER	180	106	36.7	1.70	10

Test constants and formulas for these meters are given in Chapter XV.

Data on the windings of the series coils of Model A watt-hour meters follows:

SERIES COIL WINDINGS

Duncan, Model A, Watt-hour Meter

2-Wire Meters

Model	Amp.	Strips	Wire	Turns per Layer	No. of Layers	Connected	Turns per Coil	Total Turns	Amp. Turns
E–1	2½	.....	No. 16	18	9	Series	162	324	810
"	5	.....	No. 13	13	7	"	91	182	910
"	7½	.....	No. 10	9	5	"	45	90	675
"	10	.....	No. 10	9	5	"	45	90	900
"	15	.....	No. 10	9	6	Multiple	54	108	810
"	20	.....	No. 10	9	6	"	54	108	1,080
E–2	25	.....	No. 9	8	6	"	48	96	1,200
"	50	.....	No. 6	6	4	"	24	48	1,200
"	75	14′–6″	2 strips	1	16½	"	16½	33	1,237
"	100	11′–0″	2 "	1	12½	"	12½	25	1,250
E–3	150	10′–4″	3 "	1	11½	"	11½	23	1,725
"	200	9′–0″	4 "	1	9½	"	9½	19	1,900
"	300	6′–3″	6 "	1	6½	"	6½	13	1,950
"	450	4′–6″	9 "	1	4½	"	4½	9	2,025
"	600	3′–6″	12 "	1	3½	"	3½	7	2,100

3-Wire Meters

Model	Amp.	Strips	Wire	Turns per Layer	No. of Layers	Connected	Turns per Coil	Total Turns	Amp. Turns
E–1	2½	.....	No. 16	18	9	Separate	162	324	810
"	5	.....	No. 13	13	7	"	91	182	910
"	7½	.....	No. 10	9	5	"	45	90	675
"	10	.....	No. 10	9	5	"	45	90	900
E–2	15	.....	No. 6	6	4	"	24	48	720
"	20	.....	No. 6	6	4	"	24	48	960
"	25	.....	No. 6	6	4	"	24	48	1,200
"	50	11′–6″	2 strips	1	13½	"	13½	27	1,350
E–3	75	11′–4″	3 "	1	12½	"	12½	25	1,875
"	100	8′–7″	4 "	1	9½	"	9½	19	1,900
"	150	6′–3″	6 "	1	6½	"	6½	13	1,950
"	200	4′–6″	8 "	1	4½	"	4½	9	1,800
"	300	3′–5″	12 "	1	3½	"	3½	7	2,100
"	450	2′–7″	18 "	1	2½	"	2½	5	2,250
"	600	1′–7″	24 "	1	1½	"	1½	3	1,800

Size of strips = 1⅛″ x .0016″.

Data on the windings of the series cores of other models are given on the next page.

Duncan Models E, EA, F and C Watt-hour Meters above Serial Number 150,000.

SERIES COIL WINDINGS

2-Wire Meters

Model	Amp.	Strips	Wire	Turns per Layer	No. of Layers	Connected	Turns per Coil	Total Turns	Amp Turns
E-1	2½	.....	No. 16	18	9	Series	162	324	810
"	5	.....	No. 13	13	7	"	91	182	910
"	7½	.....	No. 11	10	6	"	60	120	900
"	10	.....	No. 10	9	5	"	45	90	900
"	15	.....	No. 11	10	6	Multiple	60	60	900
E-2	25	.....	No. 9	8	6	"	48	96	1,200
"	50	.....	No. 6	6	4	"	24	48	1,200
"	75	14'-6"	2 strips	1	16½	"	16½	33	1,237
"	100	11'-0"	2 "	1	12½	"	12½	25	1,250
E-3	150	10'-4"	3 "	1	11½	"	11½	23	1,725
"	200	9'-0"	4 "	1	9½	"	9½	19	1,900
"	300	6'-3"	6 "	1	6½	"	6½	13	1,950
"	400	.....	7 "	1	5½	"	5½	11	2,200
"	450	4'-6"	9 "	1	4½	"	4½	9	2,025
"	500	.....	11 "	1	4½	"	4½	9	2,250
"	600	3'-6"	12" "	1	3½	"	3½	7	2,100

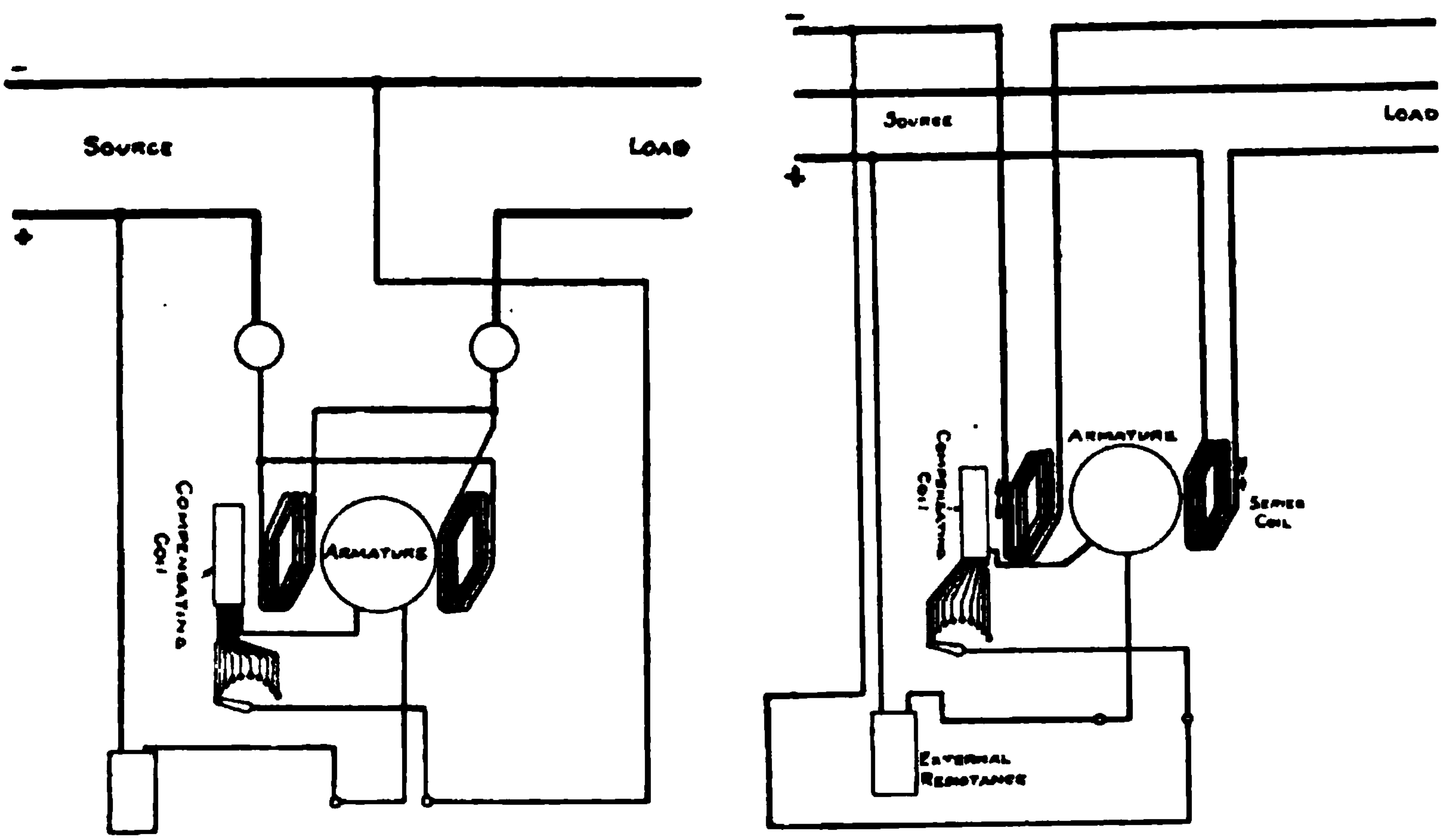
3-Wire Meters

Model	Amp.	Strips	Wire	Turns per Layer	No. of Layers	Connected	Turns per Coil	Total Turns	Amp Turns
E-1	2½	.....	No. 16	18	9	Separate	162	324	810
"	5	.....	No. 13	13	7	"	91	182	910
"	7½	.....	No. 11	10	6	"	60	120	900
"	10	.....	No. 10	9	5	"	45	90	900
E-2	15	.....	No. 7	7	5	"	35	70	1,050
"	25	.....	No. 6	6	4	"	24	48	1,200
"	50	11'-6"	2 strips	1	13½	"	13½	27	1,350
E-3	75	11'-4"	3 "	1	12½	"	12½	25	1,875
"	100	8'-7"	4 "	1	9½	"	9½	19	1,900
"	150	6'-3"	6 "	1	6½	"	6½	13	1,950
"	200	4'-6"	8 "	1	4½	"	4½	9	1,800
"	300	3'-5"	12 "	1	3½	"	3½	7	2,100
"	400	.....	15 "	1	2½	"	2½	5	2,000
"	450	2'-7"	18 "	1	2½	"	2½	5	2,250
"	500	.....	21 "	1	1½	"	1½	3	1,500
"	600	1'-7"	24 "	1	1½	"	1½	3	1,800

Size of strips = 1⅛" x 0.020".

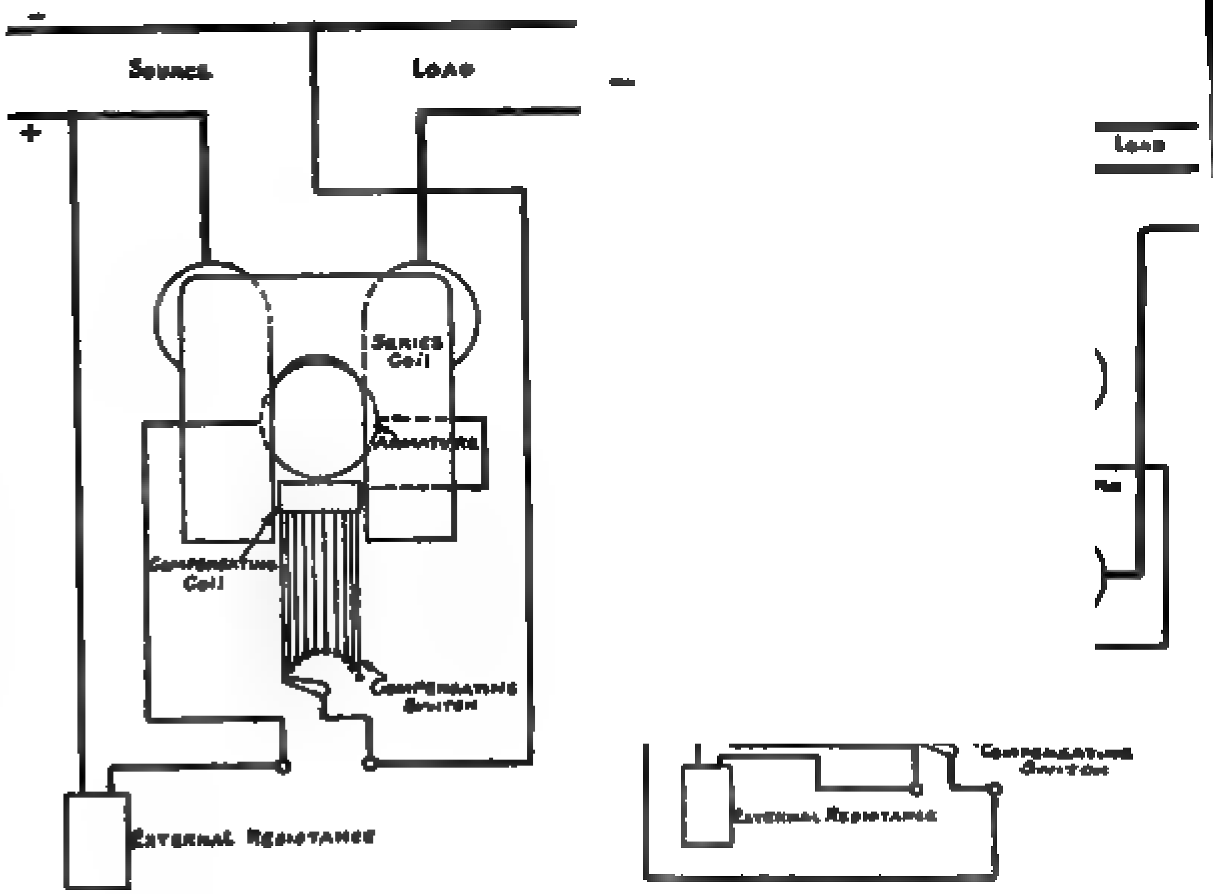
Diagrams of connections are shown in Figs. 659 to 666.
Dimensions of these meters are shown in Figs. 667 to 670.

Internal Connection Diagrams



Two-wire. Three-wire.

Fig. 659.—Internal Connections for Duncan, Model A, Continuous Current Watt-hour Meters.



Two-wire. Three-wire.

FIG. 660.—Internal Connections for Duncan, Model C, Switchboard, Continuous Current Watt-hour Meters.

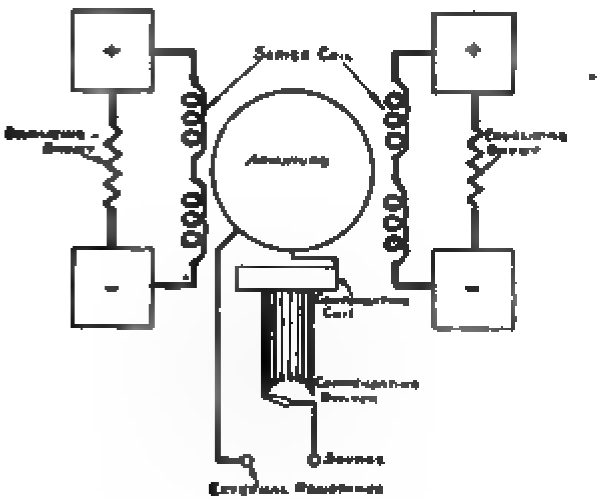
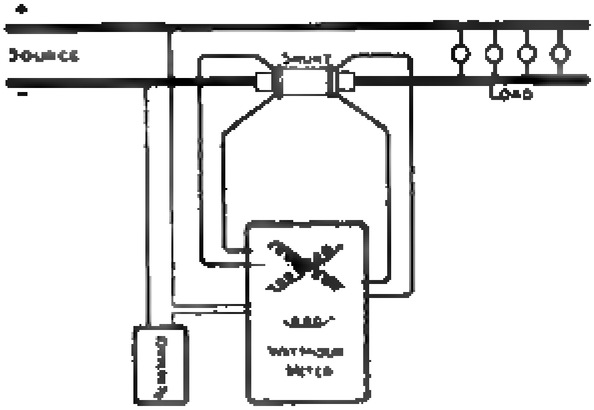
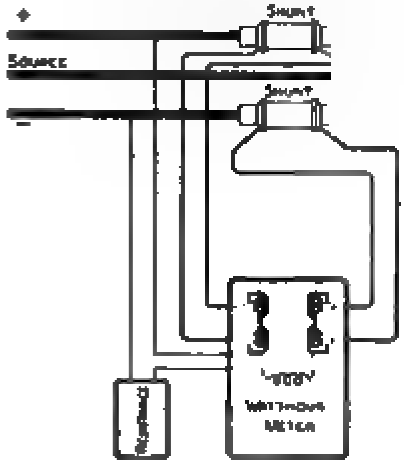


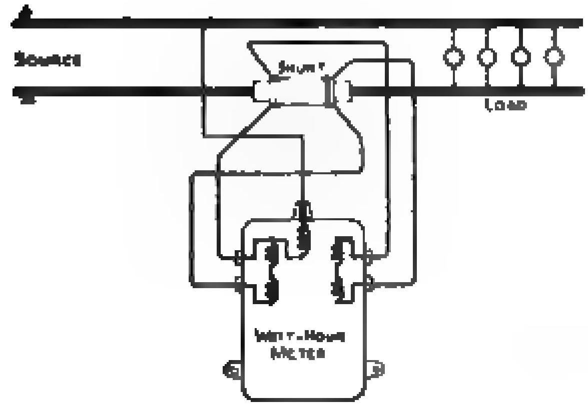
FIG. 661.—Internal Connections for Duncan, Model R, Shunted Switchboard, Continuous Current Watt-hour Meter.



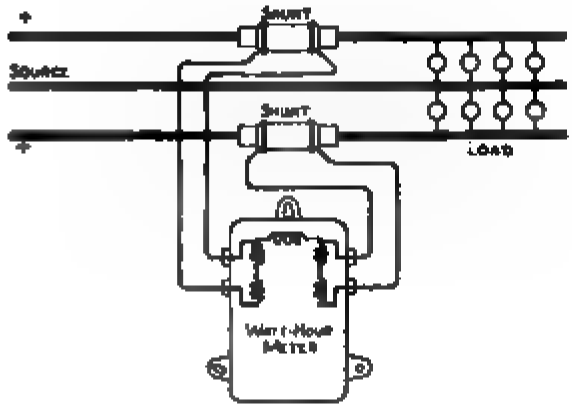
Model R, 2-wire



Model R, 3-wire.



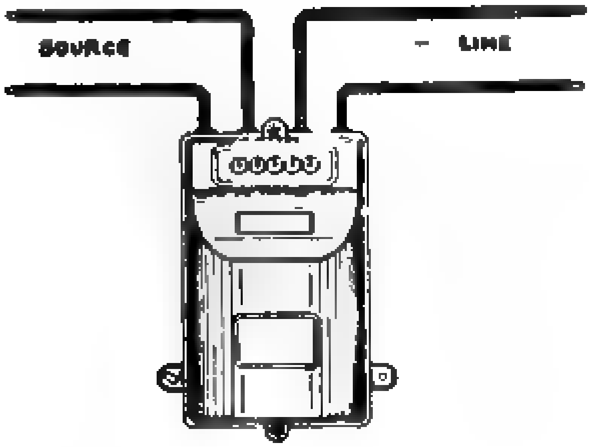
Model ER, 2-wire.



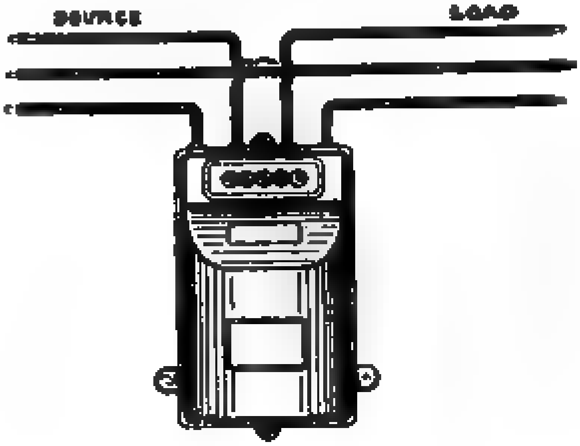
Modkl ER, 3-wire.

Fig. 663.—External and Internal Diagrams for Duncan, Continuous Current Watt-hour Meters

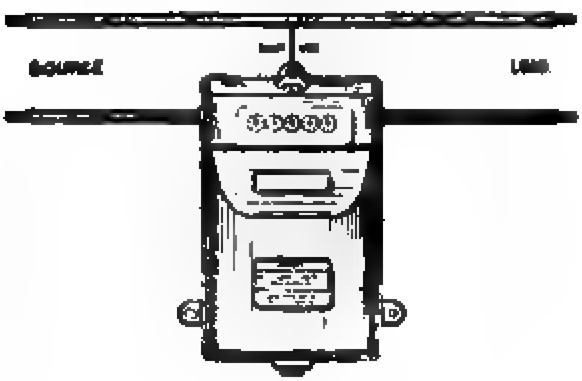
External Connection Diagrams



2 wire 4-binding Post Type, Internally Connected Shunt.



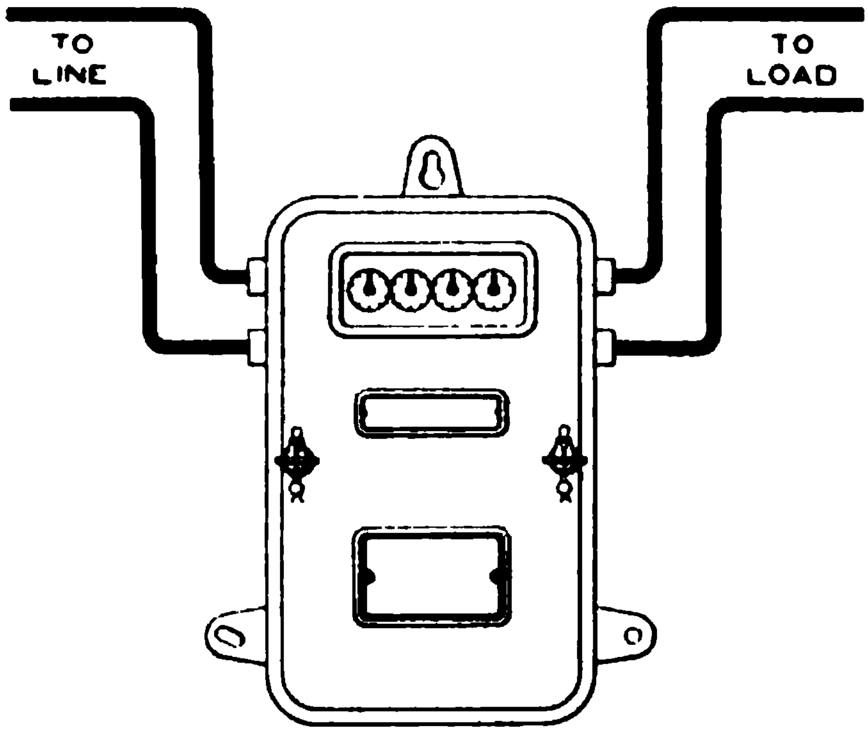
3-wire 4-binding Post Type, Internally Connected Shunt



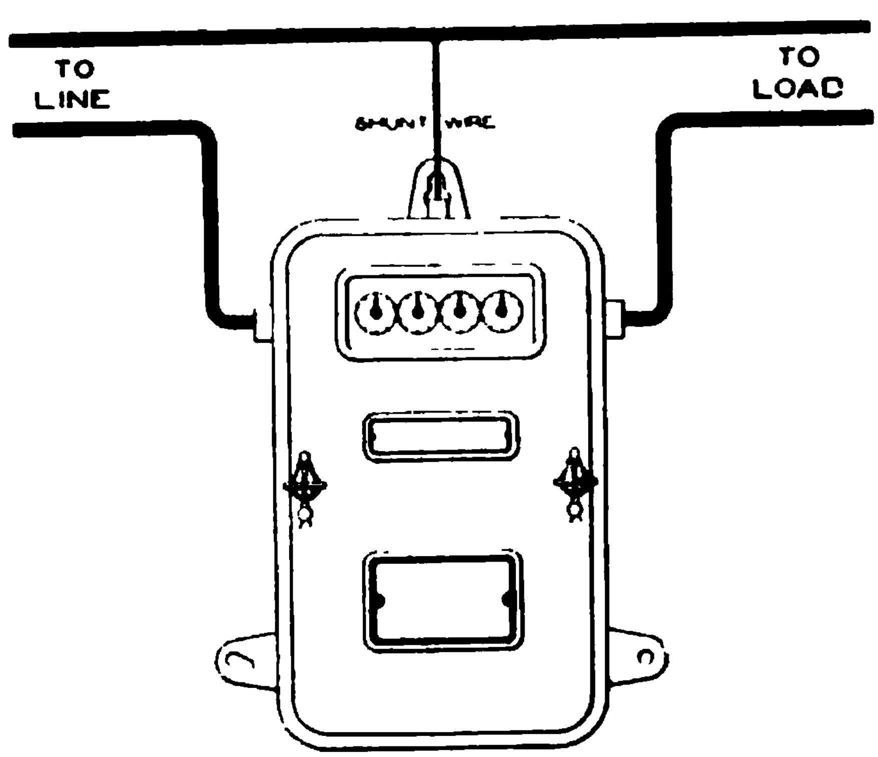
2 wire 3-binding Post Type, Externally Connected Shunt

3-wire 5-binding Post Type, Externally Connected Shunt.

Fig. 663 —External Connections for Duncan, Model A, Continuous Watt-hour Meter

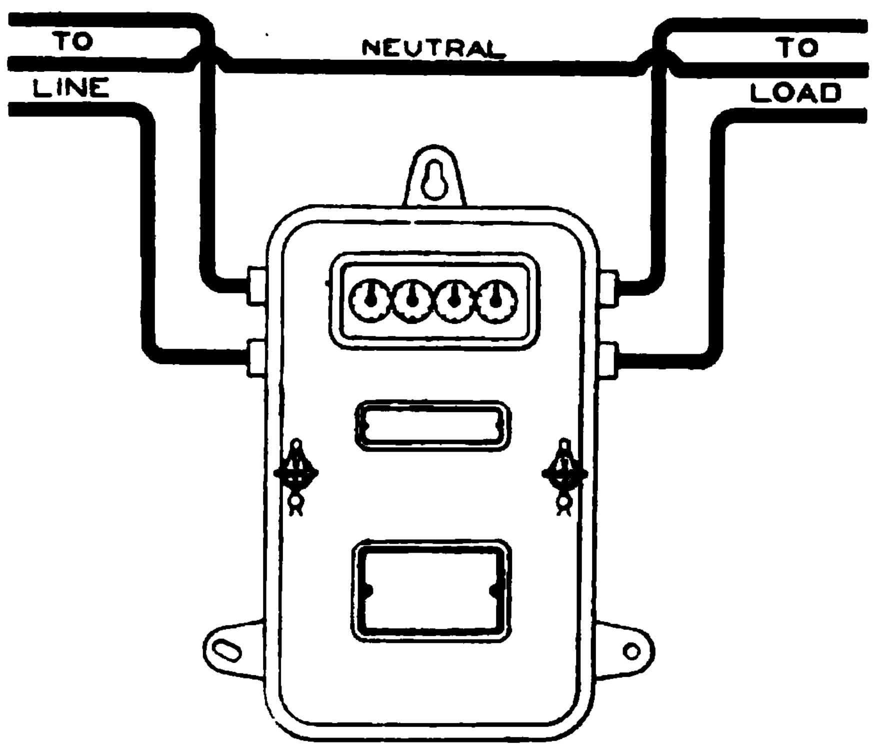


2 WIRE 4 BINDING POST TYPE
INTERNALLY CONNECTED SHUNT



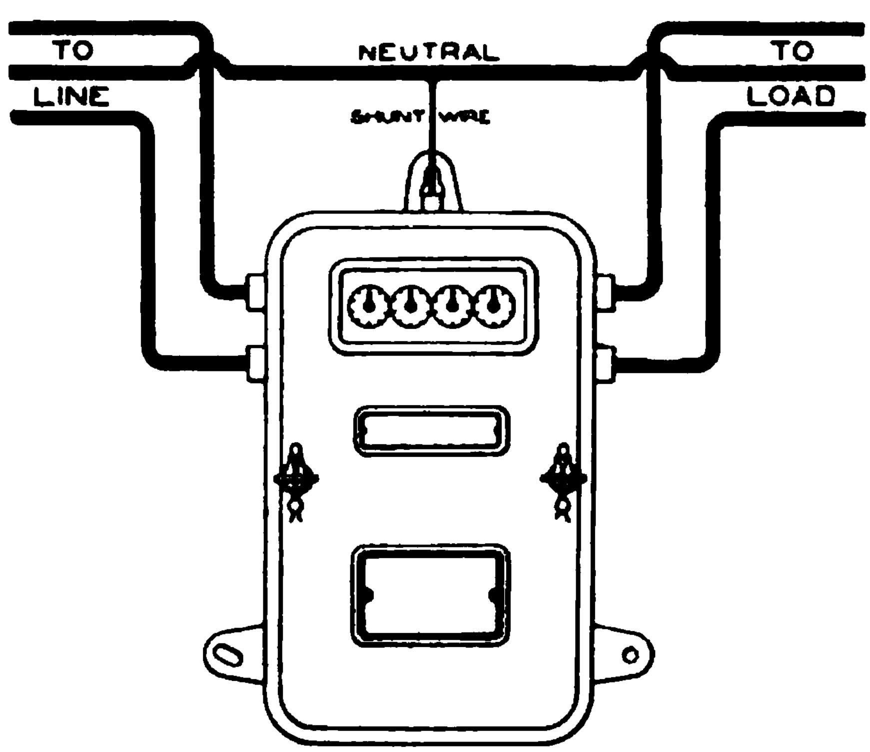
2 WIRE 3 BINDING POST TYPE
EXTERNALLY CONNECTED SHUNT

Fig. 664.—External Connections for Duncan, Model E, Continuous Current Watt-hour Meter



3 WIRE 4 BINDING POST TYPE

INTERNALLY CONNECTED SHUNT



3 WIRE 5 BINDING POST TYPE

EXTERNALLY CONNECTED SHUNT

FIG. 665.—External Connections for Duncan, Model E, Continuous Current Watt-hour Meter

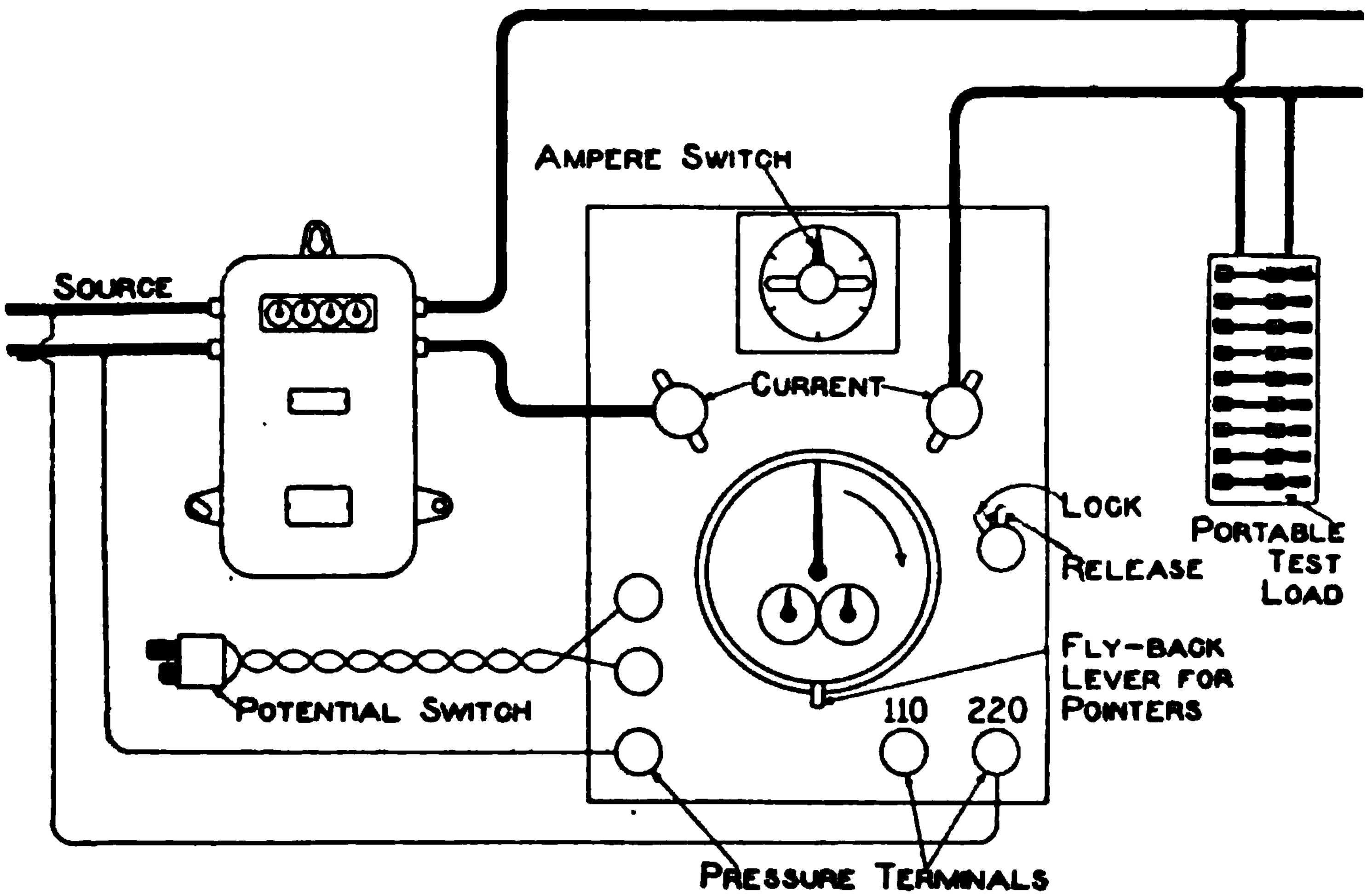
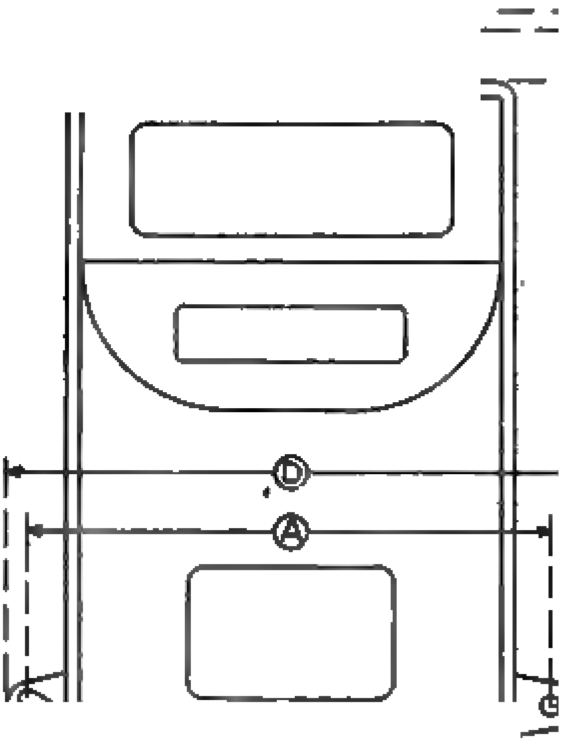


FIG. 666.—Diagram of Connections for Duncan, Model H, Rotating Standard.



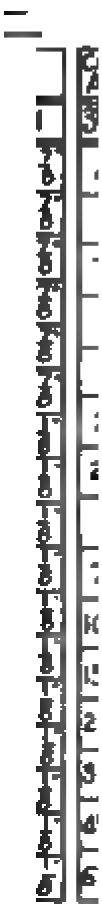
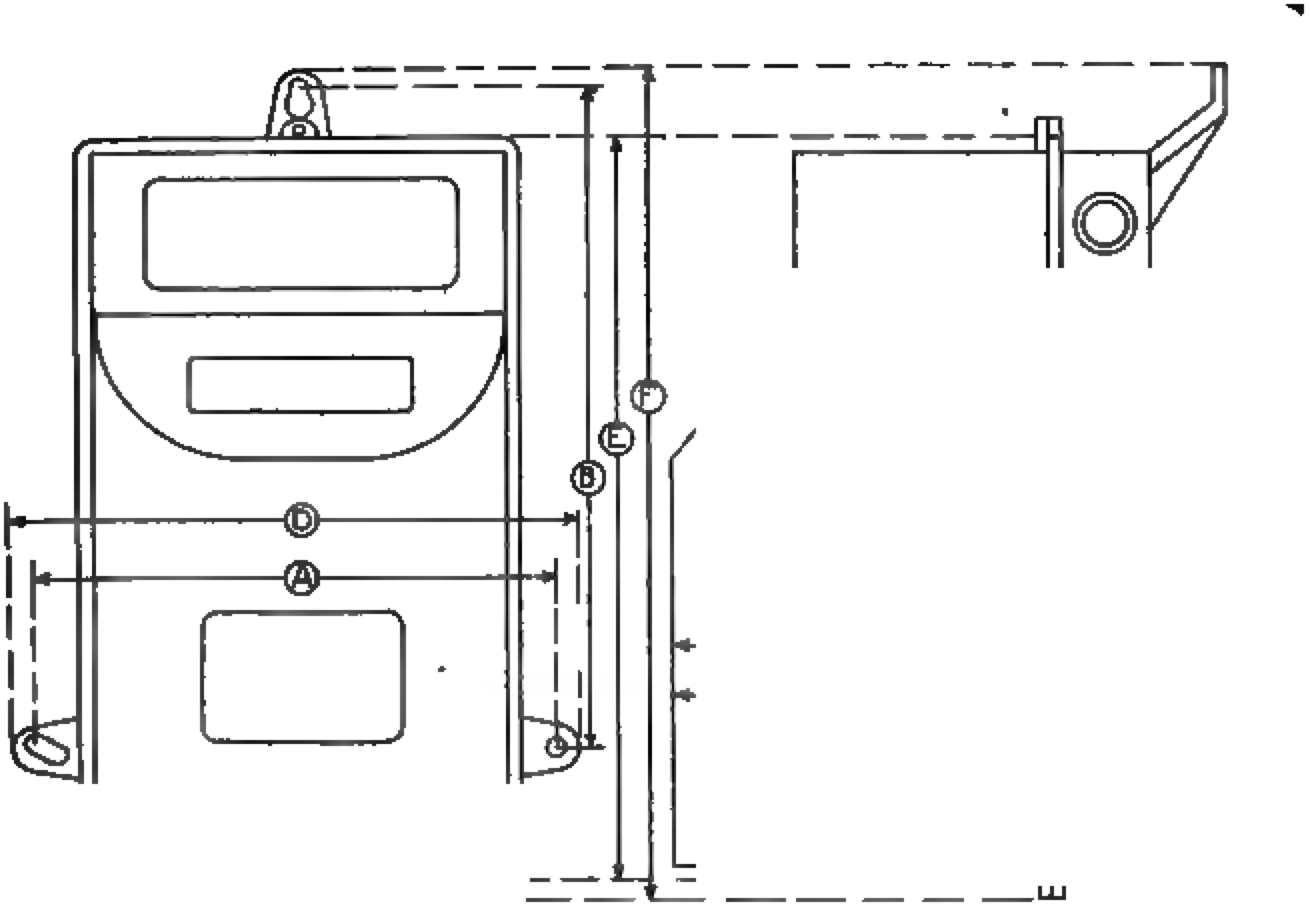


FIG. 667 —Dimensions of Duncan, Model A, Continuous Current Watt-hour Meter.



CAPACITY AMPERES	DIMENSIONS FOR 300 VOLTS								
2 WIRE	A	B	C	D	E	F	G	H	I
2½	7¼	9⅛	6⅝″	8 11/16″	10 11/16″	12⅛″	6⅝″	3	9⅝″
5	7¼″	9⅛″	6⅝″	8 11/16″	10 11/16″	12⅛″	6⅝″	3″	9⅝″
7½	7¼″	9⅛″	6⅝″	8 11/16″	10 11/16″	12⅛″	6⅝″	3″	9⅝″
10	7¼″	9⅛″	6⅝″	8 11/16″	10 11/16″	12⅛″	6⅝″	3″	9⅝″
15	7¼″	9⅛″	6⅝″	8 11/16″	10 11/16″	12⅛″	6⅝″	3″	9⅝″
20	7¼″	9⅛″	6⅝″	8 11/16″	10 11/16″	12⅛″	6⅝″	3″	9⅝″
25	8¼″	10 5/16″	7⅝″	9⅝″	11 11/16″	13⅛″	6½″	3″	9½
50	8¼″	10 5/16″	7⅝″	9⅝″	11 9/16	13⅛″	6½″	3″	9½″
75	8¼″	10 5/16	7⅝″	9⅝″	11 9/16″	13⅛″	6½″	3″	9½
100	8¼	10 5/16	7⅝″	9⅝″	11 9/16″	13⅛″	6½″	3″	9½″
150	9 5/16	11⅜″	8″	10 5/16	13⅛″	14 5/16	7½″	3″	10½″
200	9 5/16	11⅜″	8″	10 5/16	13⅛″	14 5/16	7½″	3″	10½″
300	9 5/16	11⅜″	8″	10 5/16	13⅛″	14 5/16″	7½″	3	10½″
450	9 5/16	11⅜″	8″	10 5/16	13⅛	14 5/16″	7½″	3″	10½
600	9 5/16	11⅜″	8	10 5/16″	13⅛″	14 5/16″	7½″	3	10½″

FIG. 668.—Dimensions of Duncan, Model A, Continuous Current Watt-hour Meter

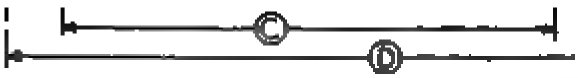
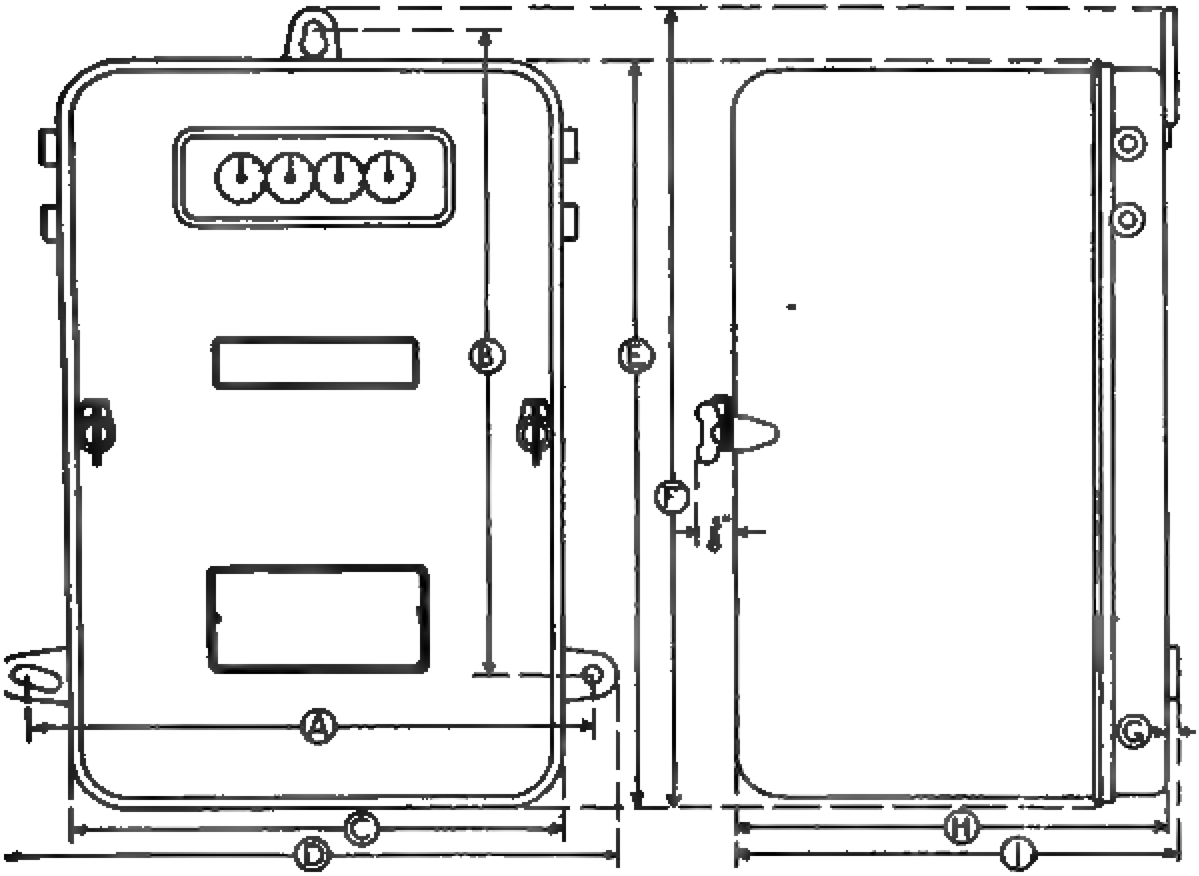


FIG 669 —Dimensions of Duncan, Model E, Continuous Current Watt-hour Meter



THIS TABLE APPLIES TO DIMENSIONED DIAGRAM ON OPPOSITE PAGE.

FIG. 670.—Dimensions of Duncan Model B, Continuous Current Watt-hour Meter

The following instructions for installing and adjusting these types of watt-hour meter were issued by the manufacturer:

After the meter is unpacked, and before the case or cover is opened clean it carefully, and see that none of the excelsior in which it was packed is adhering to the felt which projects out beyond the back edge of the cover.

When the proper location has been selected (which should be one where there is no vibration), nail, or screw, upon the wall, a board somewhat larger than the back dimensions of the meter, and upon this board hang the meter by the top hanger.

Next remove the cover, then proceed to level the meter, getting it as level as possible, because many complaints about meters being too slow on small loads are traced to the meter being "out of level."

The most practical and accurate method of leveling a meter is to use a small brass weight upon the disk as follows:

Place the weight upon the front or back upper surface of the disk and near to the edge, and note which way the disk and weight rotate. If they go toward the right-hand side of the meter, then move the bottom of the meter in the same direction so as to raise the disk on the right-hand side. When the disk is perfectly level from right to left, the weight and disk will remain stationary when placed at either the back or front. Next put the weight at either side of the disk, and should they turn toward the front, it indicates that the disk is lower at the front than at the back; then the meter should be brought out from the wall or board at the bottom until the weight remains steady at the side when placed there. If the weight should move toward the back after being placed at the side, it indicates that the back of the disk is lower than the front and the meter should be brought out from the wall or board at the top.

In leveling the meter in the last position, it is possible that the first leveling has been altered, hence it is necessary to again repeat the first leveling, and even when this is readjusted, try the second leveling again. When the meter is leveled in this manner the weight may be placed at any point upon the disk and will remain absolutely stationary.

This method is reliable, because the force of gravity which is employed never alters, while the use of a spirit level cannot always be depended upon, and particularly in the case of short levels, such as are used in leveling meters, as they are rarely, if ever, correct.

A weight suitable for this work is made from a section of brass rod ¾ inch in diameter by ¼ inch long.

When connecting the line wires into the binding posts of the

meter, exercise care in getting the screws tight so as to prevent heating through poor contact.

If, upon starting the meter, it should spark at the brushes, it is an indication that dust has lodged upon the commutator, and it should be cleaned with a piece of closely woven cotton tape ¼ inch wide.

In putting the cover into position on the meter, see that the felt is not pulled away from the inner rib and doubled over into the groove, as this will cause the cover to be higher at this point than any other point around the groove, and permit the entrance of dust.

Do not let meters remain around in the meter shop, or any other place for that matter, with their covers off. Keeping them clean will insure less trouble, and secure better service and longer life.

The method of compensating for errors on small loads adopted in this meter consists of a small multipoint switch, referred to above, secured upon the front of the back cast support of the meter and determines the torque due to the compensating coil situated within the front series field coil. If the speed of the meter should be slow on small loads, that is, 3% of the meter's capacity and under, the error can be corrected by moving the lever of the switch toward F, to the left. If the speed on small loads is too high on account of vibration, the lever is to be moved toward S, to the right.

To correct the speed on higher, or larger, loads, the magnets alone must be used; as the compensating coil and switch are employed to balance, or overcome, the friction of the bearings which interferes with small load accuracy only.

The meter is shipped with the threadless jewel post lowered enough to release the jewel from the end of the shaft of the moving element—being held in this position by a wire retaining spring which engages the side of the post. Before leveling the meter, move the wire spring a little to one side, then push the jewel post up into position and allow the spring to seat itself into the slot in the head of the jewel post.

The visual bearing permits of an inspection of the jewel and pivot while the meter is in operation. When its collar is turned so as to expose the bearings, the detachable point of the shaft may be removed with a small pair of tweezers, either through the opening in the collar or through the jewel post hole in the base of the meter. Before removing the pivot, the jewel post should be taken out so as to give more room for the operation.

The detachable pivot is not threaded, but is held in the end of the spindle by magnetic attraction and made from steel wire.

When handling the wire spring which holds the jewel post in place be careful not to pull it downward but always to one side.

If a meter has stopped it may be due to one or more of a great many causes. The armature may be open circuited as occasionally happens when it is damaged by lightning, or the same cause may not do any harm to the armature but open circuit the compensating coil or perhaps, the resistance, any one of which, of course, prevents current from flowing through the armature or potential circuit. The fact of the meter stopping may also be due to the retarding disk having become slightly loosened and slipped down on the spindle, or it may have worked up through rough handling while in transit, so that it touches one of the magnets and prevents rotation.

Again, the meter may not operate on account of the person installing it having neglected to raise the jewel up into its proper place, thereby allowing the lower portion of the disk hub to rest on the top of the tubular guide in which the jewel post is positioned. Of course, in cases where the potential circuit is open, no load will cause the armature to operate, but where the position of the disk on the shaft has been altered, or the lower jewel not raised up, the meter will not operate on small loads, such as one or two lamps, but when the higher loads are applied to it, it may rotate, but too slow, consequently oversights of this sort can readily be detected.

Cases, too, have been reported where the shaft or spindle of the meter was bent while being shipped, and this caused the armature to touch some of the corners of the series field coils, but when this happens it is always best to return the meter to the factory where it can have the best attention, unless the central station manager is prepared to remedy the trouble himself.

Further, cases have been known where the potential circuit was all right, but still the meter failed to operate, due to the commutator and brushes having become so badly tarnished and dirty that the small amount of current employed was unable to pass through the dirt on the commutator. Therefore it is always well to see that the commutator and brushes are clean before undertaking to locate the trouble in any of the other parts or elements comprising the potential circuit. Such cases as this, however, are very rare.

Again, we advise examining the worm and worm wheel, for if they happen to be jammed too tightly together and bind, the meter may fail to operate, and if they are too loose, it may prove to be just as bad if the leaves of the worm should bind tightly against the edge or face of the teeth of the worm wheel. The proper meshing of the worm and worm wheel should be carefully observed, and the ideal

condition is one in which the teeth of the worm wheel just enter to one-half the depth of the leaves on the worm. When this adjustment has been properly made, there will be a small amount of freedom or lost motion between the worm and worm wheel, but not enough to permit the teeth of the worm wheel to slip past the leaves of the worm.

It sometimes happens that the upper bearing has been driven down on the shaft so as to press the shaft down on the lower jewel bearing, or so that the disk hub rests on the jewel post. This will cause erratic light load readings, or may stop the meter altogether, but can be easily corrected by raising the upper bearing so that the shaft will have a vertical adjustment or clearance of about $\frac{1}{16}$ of an inch.

If the meter runs unsteady, or jerky, it may be due to excessive friction, or it may be caused by a defective armature or commutator. If due to friction, the trouble will be more noticeable on the lighter loads, the speed of the meter may vary; some being made with the disk running steadily, others very jerky. If the trouble is in the armature the disk will usually run the same for each revolution, slowing down or speeding up at the same point each time.

The source of friction may be easily eliminated, but some sort of a test must be made on the armature. A defective armature may have an open circuited coil, two or more commutator segments short circuited together, or some of the leads connecting the coils to the commutator segments may be broken.

For testing out the armature, a convenient test lamp may be connected up and used on 110 or 220 volts as follows: Take a 16 C.P. lamp provided with a key socket and about three feet of lamp cord, and connect one of the ends of the lamp cord to one side of the circuit, then to the other side of the circuit connect a piece of single conductor lamp cord which will now give the two terminals, that is, one coming from one side of the supply circuit and the other one coming from the key socket. To each of these two terminals attach a piece of $\frac{1}{16}$ inch brass wire made with a point and covered with some kind of insulation, so that they may be properly handled, leaving only one-half or three-fourths of an inch of the pointed ends exposed.

These two pointed ends are brought into contact with two adjoining segments, and if the coil between these two segments is all right the lamp will light up with a subdued incandescence. Then connect one of the pointed terminals to one of the segments already touched, and with the other pointed terminal make contact with the next segment, and so on around the entire commutator. If all of

the coils are in good shape, the lamp will burn with about the same dull incandescence on all of the coils. If one of the coils between two of the segments causes the incandescence of the lamp to be very low, then this shows that that particular coil is open circuited, and the fact of the lamp burning much duller is due to the current having to pass around all of the other coils in series instead of going around two paths of the armature in parallel as is the case when the armature is O. K.

Next, place the ends of the testing pins on the terminals at the end of the brushes, which are mounted on the lava brush block, and slowly revolve the armature. If the coils are all right, the lamp should burn at a low incandescence during the entire revolution of the armature, but if the lamp burns brightly, or flames up, there is a short circuit between some of the armature coils or commutator segments.

Another good test to make in order to ascertain whether or not some of the segments are grounded to the clamping rings of the commutator, is by touching one of the rings with one of the testing pins and allowing the other to touch each segment successively, then repeating the test with the second clamping ring.

It is easy to find trouble in the compensating coil by placing the pointed testing terminals at the ends of the compensating coil, one of which is connected to the lower left-hand series binding post and the other to one of the brush terminals on the lava support. These two terminals are easily observed on account of both of them being covered with colored sleeving, either red and black or red and green. If the lamp lights up when the testing terminals are applied to the ends of these two colored leads, the compensating coil is all right, but if it is open circuited, the lamp will not show any incandescence. In making this test, it is well to move the lever of the compensating switch over all of the contacts, that is, from F to S, but be careful to put it back where it originally was when you started to make the test, so as not to alter the compensation. In making these tests it is understood that the meters are disconnected from the circuit.

In testing the resistance for an open, or break, touch its terminals with the testing pins, and if is open circuited in any of its coils, the lamp, of course, will not light up. If the resistance is as it should be, the lamp will burn with a low incandescence. If it is open circuited, next proceed to find out the particular section or coil in which the break is. This can be done by removing a little insulation from one of the wires on each coil and testing them one at a time. The break

can be easily repaired by unwinding that section in which the trouble has been located, and soldering the ends together.

In the case of 220 or 500 volt resistance cards a more satisfactory test can be made by ringing through them with an ordinary magneto. The comparatively high ohmic resistance of the cards supplied with meter of these voltages is sufficient tó prevent the test lamp lighting up, but is not high enough to prevent a good magneto ringing through them if they are not open circuited.

The wire employed in winding up these resistances gives very little trouble from open circuits, and when they are found, it may be attributed to the action of lightning.

Duncan Alternating Current Watt-hour Meters

Description of Model

Model M

The Duncan Model M watt-hour meter (Fig. 671) is of the induction type. It contains but three coils, one being a potential coil,

Fig. 671.—Duncan, Model M, Single-phase, Induction Watt-hour Meter.

the other two being series coils. The meter is phased by having in multiple with the main, or effective, air gap another air gap. The effective gap, or the one in which the disk operates, is longer than

the gap in multiple with it and this, together with the reactance of the braking disk itself, is sufficient to secure the required quadrature. All light load adjustment is secured by another application of a general scheme of multiple gaps. Small soft iron cores are carried on sliding adjustments in front of the potential circuit cores, giving a starting, or compensating, torque. To prevent humming, the shaft is provided with a flexible upper bearing. The instrument contains one brake magnet and full load adjustment is secured by shunting the flux of this magnet with a soft iron disk whose position can be changed by micrometer adjustment. This meter is provided with four dials of the same size as all other Duncan watt-hour meters. The binding posts are contained in a separate compartment located at the bottom of the meter. When ordered for 133 cycles, a special adjustment is provided so that the meters can be changed over to 60 cycles without recalibration.

Diagrams of connection for this meter are given in Fig. 672.

Dimensions of this meter are given in Fig. 673. This meter is made in all sizes from 5 to 800 amperes inclusive with series transformers used with all instruments from 100 amperes up.

Test constants for this type of meter are the same as for the Model E house type meters.

This model was produced in February, 1912.

The Model M watt-hour meter has a torque of 115 mm-g.; a weight of moving element of 46 grams; a full load speed of 36.7 rev. per min.; a ratio of torque to weight of 2.5 and a potential circuit loss, on 110 volts, of 1.25 watts.

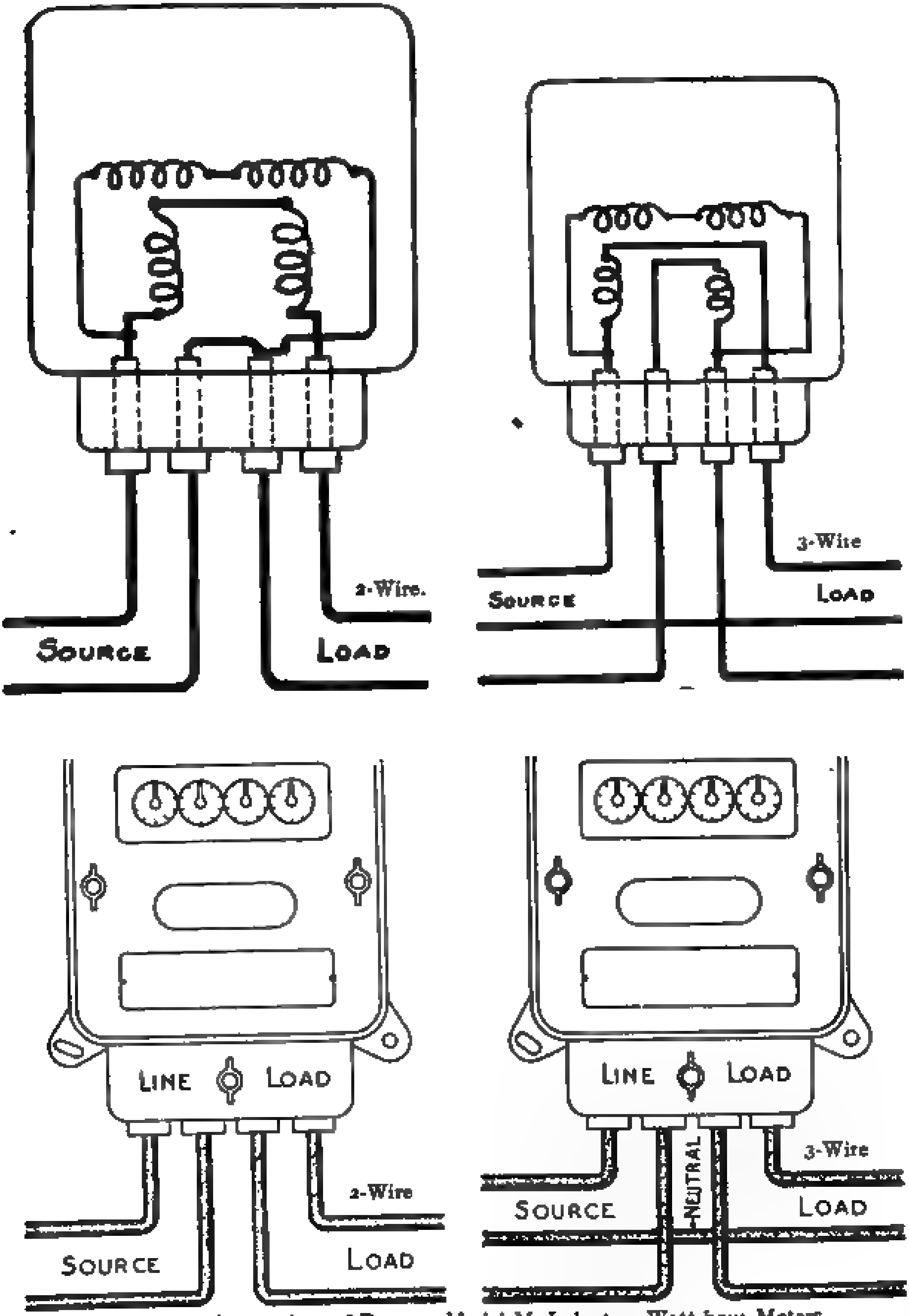


FIG. 672.—Connections of Duncan, Model M, Induction Watt-hour Meters.

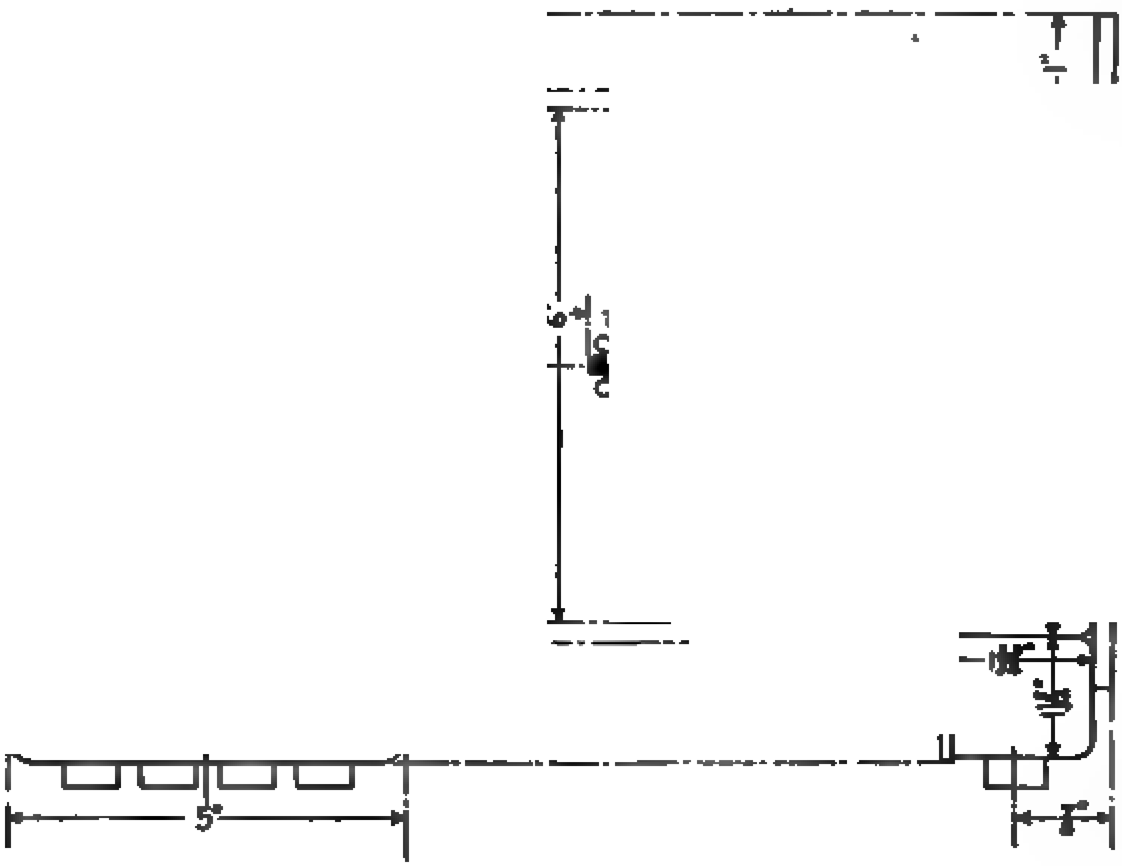


FIG. 673.—External Dimensions of Duncan, Model M, Induction Watt-hour Meter.

COLUMBIA CONTINUOUS CURRENT WATT-HOUR METERS

The **Columbia continuous current watt-hour meter is** of the motor type, having a light armature, carrying a current whose strength varies with variations in line potential, and revolving within the magnetic field of a stationary winding which carries a current varying with the electrical load. The torque of this meter is proportional to the product of the line potential and current, and by appropriate braking means, the speed of rotation is proportional to the load. A simple revolution counter attached to the armature shaft will, therefore, record the total energy which has passed (Fig. 674).

Description of Various Types

Type D

In the **Columbia Type D,** service meter, the armature windings comprise but three coils. These are approximately circular in shape and are form-wound, interlocked with one another, and with the light impregnated fiber disk which serves as a spacer for them (Figs. 675 and 676).

The objectionable non-uniform torque, which the earlier efforts to construct a satisfactory **three-coil armature** encountered, is overcome by a simple expedient. The aluminum damper disk has the conventional anti-creep provision in the shape of three small soft-iron plugs, mounted close to the central shaft. These in their revolution come successively within the influence of an adjustable iron screw which is magnetized by an extension from one of the damper magnets. The angular relationship of the armature windings and of the three iron plugs is such that at the time that the armature is exerting a maximum torque the magnetized screw is exerting the maximum pull to hold back a given plug, and conversely when the armature pull is a minimum the magnetized screw is attracting the plug with the maximum effort to cause forward rotation. The irregularities of torque are in this way smoothed out.

The construction of the brushes and brush holder will be evident on referring to Fig. 677, which shows a pair of brushes with their supporting plate. It will be noted that each brush is formed of a length of phosphor bronze wire bent hairpin-wise and secured at its "U" shaped extremity to a brass sleeve, which in turn is secured to an insulated stud by the set screw "A." This same sleeve carries at its upper extremity an extension "B" at the end of and at right

T_4

T_1

FIG. 674 —Internal Connections of Columbia, Type D, Continuous Current Watt-hour Meter *A*, Armature; *AR*, Adjustable Resistance to Vary the Field of *CC*, BB_1, Brushes, *C*, Commutator, *CC*, Friction Compensating Coil; *D*, Disk, *FLA*, Full Load Adjustment, *LL* or *CA*, Light Load or Creep Adjustment; MM_1, Magnets; *R*, Resistance, *S*, Shaft, *SFC* Current or Series Coil, T_1-T_4, Terminals.

FIG. 675.—External View of Columbia, Type D, Continuous Current Watt-hour Meter.

FIG. 676.—Moving Element.

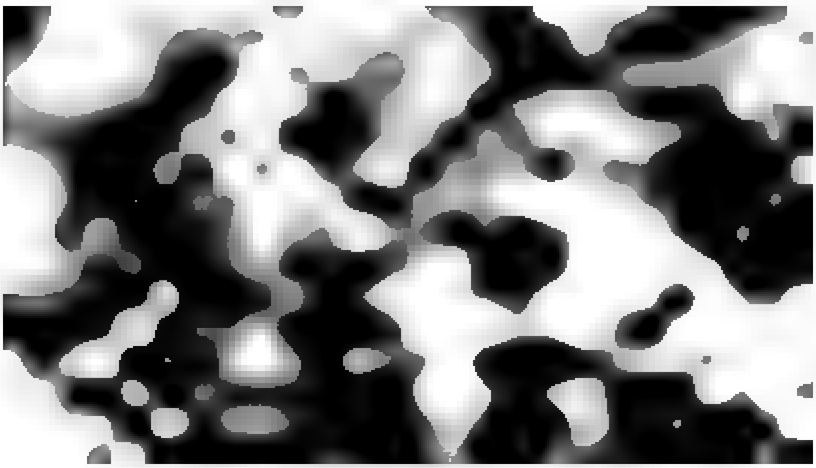


FIG 677.—Commutator Brushes.

angles to which there is the micrometer screw "C." The end of this micrometer screw bears against an insulated stop "D." The phosphor bronze wire, of which the hairpins are formed, is rolled flat for the main proportion of its length so as to form a delicate spring and its rounded free ends serve to receive the silver tubing which, when slipped over them, forms the brushes proper. Obviously, with such a structure the micrometer screw by regulating the distance between the extension "B" and the insulated stop regulates the pressure with which the brushes press against the commutator and this pressure when once determined is invariable. If it is at any time desired to completely remove the brushes for inspection purposes all that need be done is to loosen the screw "A," whereupon the brushes may be rotated clear and dropped out into the hand of the inspector. The reverse operation upon reassemblage leaves the brush tension unchanged.

The **Columbia commutator** contains only three segments, is one-tenth of an inch in diameter, and is made of chemically pure silver. The shaft is of solid bronze and the pivots are of hardened steel, ground and polished to the proper curvatures and secured in place by split-friction clamps, which enable their instant removal and replacement without the aid of tools other than a pair of tweezers. **The jewel,** which is of sapphire, is fastened solidly in the end of a plain cylindrical post, having a head at the bottom larger than its body. The bracket to receive this post, instead of being threaded, is drilled with a smooth hole of the same diameter as the post body. A flat phosphor-bronze spring of appropriate strength is fastened so that its end may be brought under the post end, as shown in Fig. 678, serving, then, both as the retaining means and as the jewel spring. With this design when it is desired to remove a jewel for inspection, the spring end is pulled down and simultaneously swung aside with the thumb, whereupon the jewel drops out free and clear into the hand. Its replacement involves the reversal of this procedure (Fig. 679).

The drag magnets being clamped and doweled in place, it is not possible to use the common expedient of shifting them in and out on the base plate to vary the lever arm with which the eddy currents set up in their damper disks act, thus varying the damping effect, and, hence, the main speed. The same end is accomplished by providing a soft-iron bridge plate, bridging over the extremities of each magnet and adjustable by means of a set screw and lock-nut to any desired distance therefrom. This gives a regular micrometer means of varying the effective magnet strength.

A heavy **soft-iron shield** is interposed between the series coils and the permanent magnets, which guards the magnets from disturbances from short circuits.

In all electricity meters which contain moving parts there is provided a means of impressing a small but constant turning effect on the system so as to compensate for the inevitable friction. In commutator type meters this means commonly takes the form of a coil of fine wire which

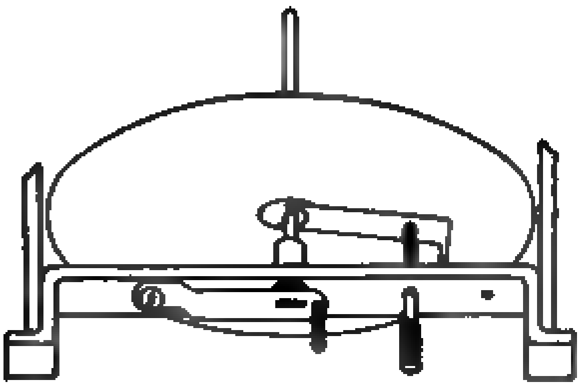


Fig. 678.—Method of Supporting Bearing and Locking Moving Element.

Fig 679.—Internal View of Columbia, Type D, Continuous Current Watt-hour Meter showing Method of Removing Bearing.

is placed adjacent to the series coils and connected in series with the armature. Being placed as is the series coil, its field evidently acts upon the armature much as the series coil does. This tendency may be modified in strength for adjustment purposes, either by varying the distance by which the fixed coil is removed from the armature, or by varying the current through the two. In the Columbia meter the last named expedient is the one adopted, the coil being permanently secured. The current adjustment is obtainable by providing in the coil circuit a series of small resistance spools, equipped with pin terminals, to which con

nection can be selectively made by means of a split bushing terminal on a flexible cord. This series of spools is strung on a metal arbor accessibly located within the case

The registers which are regularly supplied are of the standard type, but for those who prefer it, a cyclometer register can be furnished (Fig. 680)

The base is a solid aluminum casting, ribbed so as to secure required stiffness and at the same time being light The covers are likewise of aluminum, each being formed of a single stamping from the solid sheet and provided with a large, clear window, through which the dials and the disk may be observed.

Aging of the magnets, or lack of ordinary care, are the **general**

Fig. 680.—Cyclometer Register.

conditions which will cause this **meter to run fast.** The general condition which will cause this **meter to run** slow is sparking at commutator, caused by dirt, or roughness, which should be cleaned and polished with a soft piece of cotton tape or with a very fine piece of worn crocus cloth, if the tape will not remove the foreign matter Great care should be taken not to scrape the commutators or to use coarse emery paper on the same, as the fine silver particles clog up the commutator slots and short circuit them. Friction due to defective jewels, or pivots, and dirt collecting at upper bearing; also bent upper bearing pins, will cause meters to run slow.

All coils and circuits have independent terminals so that they may be readily disconnected for testing purposes. The spools on which the resistance wires are wound are of porcelain and the wires themselves, in addition to the conventional insulation, are coated with insulating compound. All parts are manufactured on the interchangeable part system.

The following formula is used for this type of meter:

$$\text{Watts} = \frac{\text{Rev.} \times K}{\text{Seconds}},$$

where "watts" represents load on the meter under test; "rev." represents the revolutions the meter makes during test; "K" is the watt-second constant of meter under test, and "seconds" is the duration of test.

Tables in Chapter XV give the gear ratios, constants and test formulas for this type of meter and the following tabulation gives additional information pertaining to this meter.

Speed at full load	30 rev. per min.
Torque at full load	90 mm-g. at 1100 watts (full load).
Weight of moving element	90 g.
Ratio of torque to weight	1.0.
Volts drop in series coil at full load	0.55 volts at 10 amperes.
Watt loss in series coil at full load	5.5.
Watt loss in potential circuit	2, at 110 volts.
Temperature coefficient per degree C.	0.12 per cent meter running faster at higher temperatures.
Continuous overload rating	1.5 times rated capacity.
Ohms resistance and size wire of shunt resistance	No. 36 B. & S. gauge German Silver (30 per cent) single silk resistance wire 3,000 ohms.
Armature coils	3 coils each of No. 40 B. & S. gauge black enameled magnet wire—2100 turns 2660 ohms.
Light load compensating coil	No. 36 B. & S. gauge black enameled magnet wire—2100 turns 450 ohms.

Amperes of Meter Capacity	Diameter of Holes in Terminal Blocks (in Inches) Wire Hole	Ins. Hole	Ampere Turns 2-Wire	3-Wire
5	3/16	7/16	665	630
10	3/16	7/16	700	600
15	3/16	7/16	660	600
25	3/16	7/16	675	600
50	5/16	5/8	600	600
75	3/8	5/8	900	900
100	3/8	11/16	800	800
150	Cable leads used		900	900
200	Cable leads used		800	800
300	Cable leads used		1,200	1,200

The sizes of this meter range from 2.5 amperes to 300 amperes, inclusive, for 100 volt, 200 volt and 500 volt, two-wire meters, and for 200 volt, three-wire meters.

This meter was produced in 1908 and slight modifications in mechanical details were made in 1909.

Type SA

The development of the **Type SA, shunted, astatic, commutator type,** watt-hour meter has been made possible by a particular design

FIG. 681.—Columbia Type SA. Shunted Astatic, Continuous Current Watt-hour Meter.

FIG. 682.—Moving Element.

of the motor element. As in all commutator type meters which are in general use in this country, the series current passes through stationary field coils and the potential circuit current, through the rotating armature, but the shape and arrangement of the coils is quite different (Fig. 681).

As will be seen from Fig. 682, which shows a **Columbia moving element** removed from the meter, this element consists of a shaft carrying at its upper extremity a pair of very light aluminum disks which support the motor element, the conventional thick aluminum disk, which acts as damper by its rotation through the air gaps of a group

of permanent magnets, being located near the lower end of the shaft. The armature windings of the motor element are a group of six cylindrical spools arranged between the two upper disks close to the central shaft and with their axes parallel thereto. Extending through each spool is a thin strip of silicon steel with its ends bent out at right angles so as to extend radially along the lower surface of the upper and the upper surface of the lower disk. These radial extensions are split so as to divide the flux more evenly around the disk circumferences and serve as the means of efficiently carrying that flux right into the interior of the stationary series windings located so as to embrace them. The material of which the magnetic strip is made and its dimensions are such as to make hysteresis and eddy current effects negligible.

The torque which is obtained with this design is high, the standard instrument at 120 volts showing, for example, about 170 millimeter-grams.

The **field ampere turns,** at rated capacity, is 240 ampere-turns for both two- and three-wire meters.

The above described design of this Columbia watt-hour meter motor element is **inherently astatic.** This astaticism follows because the connections of the series coils are such as to cause the magnetic flux to flow through each element of a pair in opposite directions. Consequently, if there is a stray field which tends to strengthen the flux through the one coil of the pair, that same field acting on the other coil, tends to weaken it an exactly like amount with the obvious net result of leaving the total unchanged. In other words, this meter can be placed in magnetic fields of fluctuating, or steady, value without having its accuracy in any way impaired; nor can these fields affect the strength of the permanent magnets within whose field the damper disk revolves, as these magnets are protected by a heavy soft-iron shield.

Cupped diamonds are used exclusively for the lower bearings.

The light load adjustments for this meter are made the same as for the Type D meter.

All **standard shunts** are made **interchangeable** and give a drop of 75 millivolts with meter attached to the shunt terminals and full load current flowing. Any standard shunt of a given capacity may thus be used with any standard meter of like capacity. Further than this, in the larger sizes—i. e., upward of 500 amperes, any standard meter can be used on any standard shunt, irrespective of capacity and will give correct indications by the employment of a simple multiplying constant.

Standard meters are all adjusted so as to require exactly 5 amperes at their full load current.

The standard lead length is 5 feet, and a pair of such leads is supplied with each two-wire meter and two pairs with each three-wire meter.

Each shunt has, in addition to the main terminals, for attachment to the bus-bars or cable lugs, and the studs for attachment of the meter shunt leads, terminals to which the shunt leads of an indicating instrument may be secured. Manufacturers of indicating instruments will supply these without shunts, adjusted to any specified drop, so that but a single shunt equipment is required.

The Standard, Columbia, shunted, astatic, switchboard watt-hour meter is finished in the rectangular case with satin finish aluminum base and beveled glass cover. The connections are invariably in the rear—i. e., there are back connection studs and the watt-hour meter is designed to be secured to the switchboard by similar studs.

The sizes range from 5 to 20,000 amperes inclusive and in the customary steps of rated capacities for 100/150 volt, 200/250 volt and 500/600 volt, two-wire meters, and also for 200/250 volt, three-wire meters.

This type of meter was produced in 1910.

The internal connections of the Columbia continuous current watt-hour meters are given in Figs. 683 and 684, and the dimension diagrams in Figs. 685 to 687.

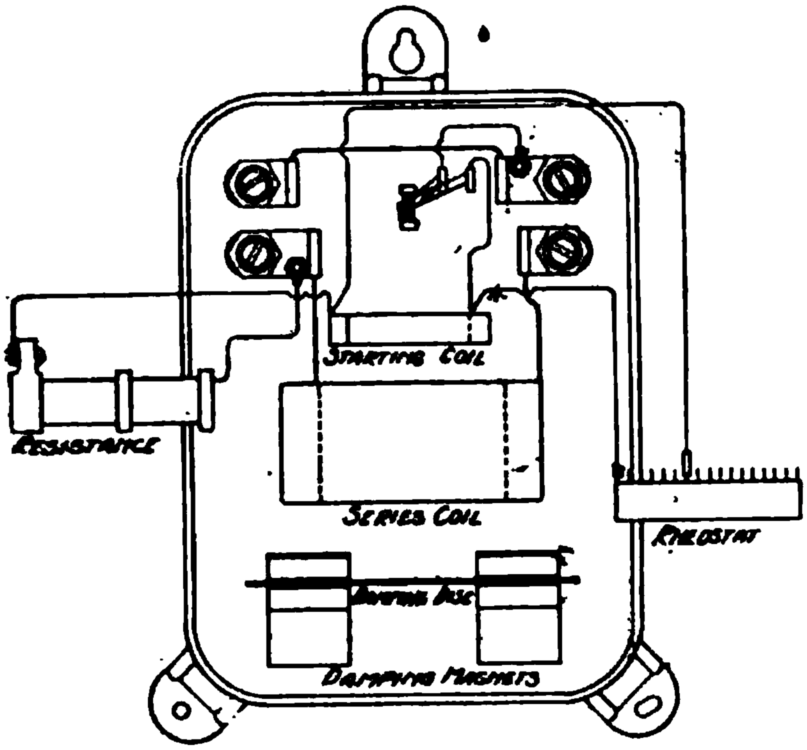


DIAGRAM OF INTERNAL WIRING OF TYPE D METERS
2 WIRE · 100 VOLTS
5 TO 75 AMPERES INC.

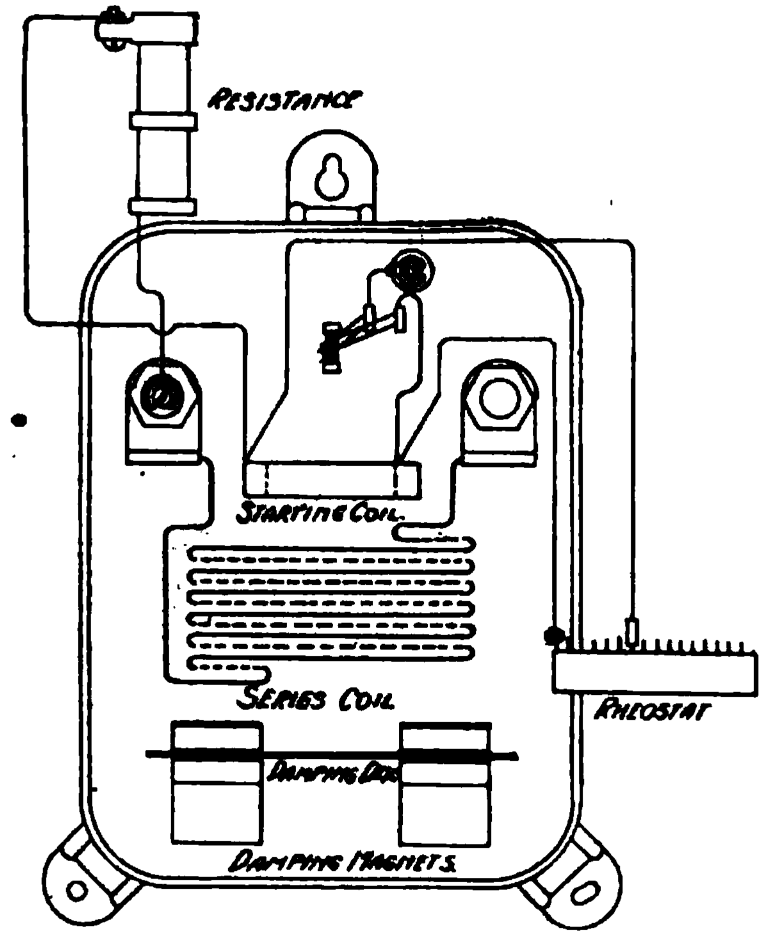


DIAGRAM OF INTERNAL WIRING OF TYPE D METERS
2 WIRE 100 VOLTS
100 TO 300 AMPERES INC.

WIRES A-A CONNECT TO RESISTANCE ON THE BACK.
RESISTANCE IS SIX SPOOLS IN SERIES.

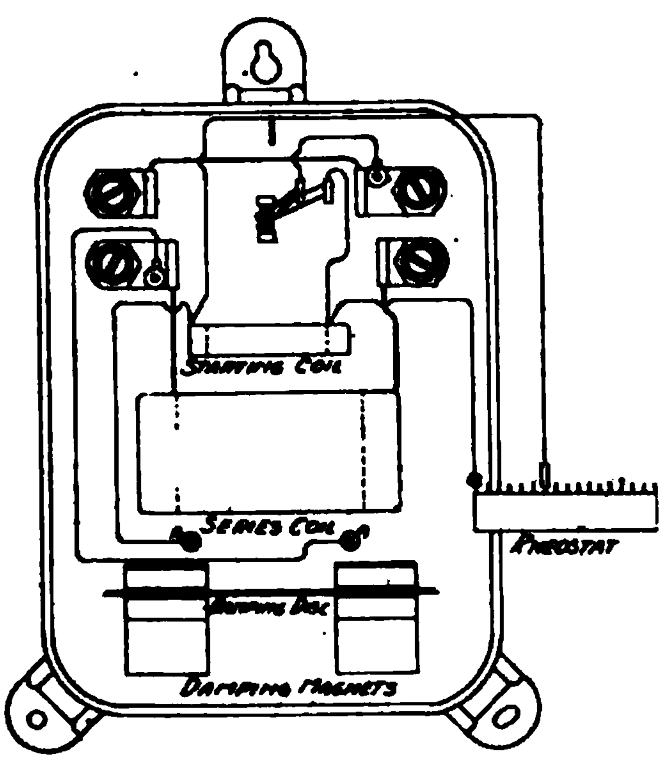


DIAGRAM OF INTERNAL WIRING OF TYPE D METERS
2 WIRE 500 VOLTS
5 TO 75 AMPERES INC.

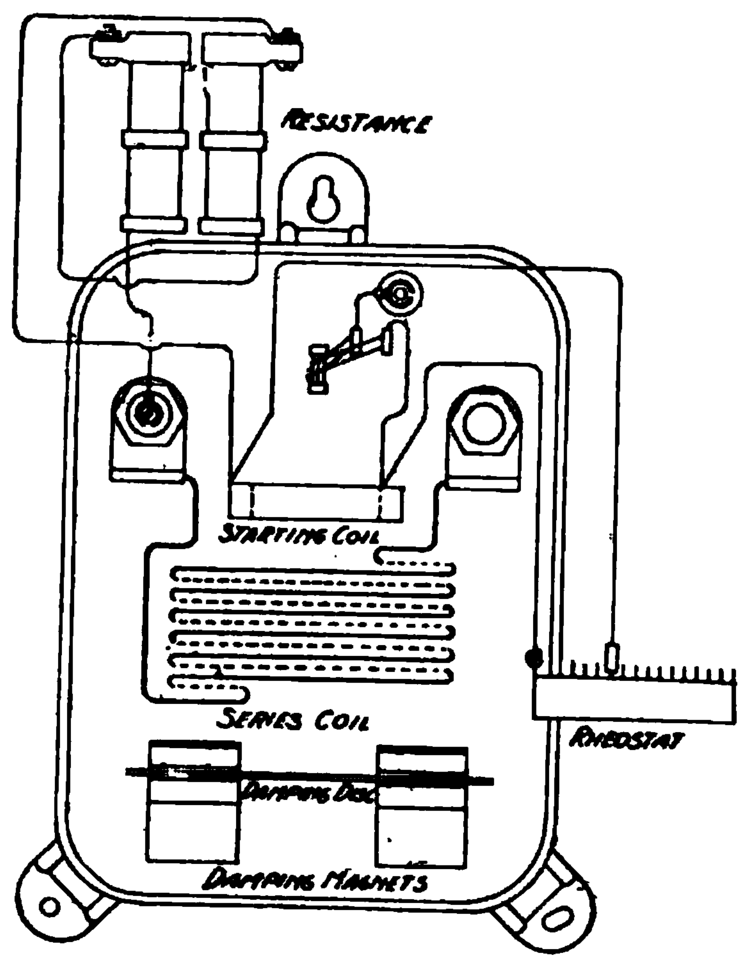


DIAGRAM OF INTERNAL WIRING OF TYPE D METERS
2 WIRE 200 VOLTS
100 TO 300 AMPERES INC.

FIG. 683.—Internal Connections for Columbia, Type D, Continuous Current Watt-hour Meters.

WIRES A-A CONNECT TO RESISTANCE ON THE BACK:
RESISTANCE IS SIX SPOOLS IN SERIES.

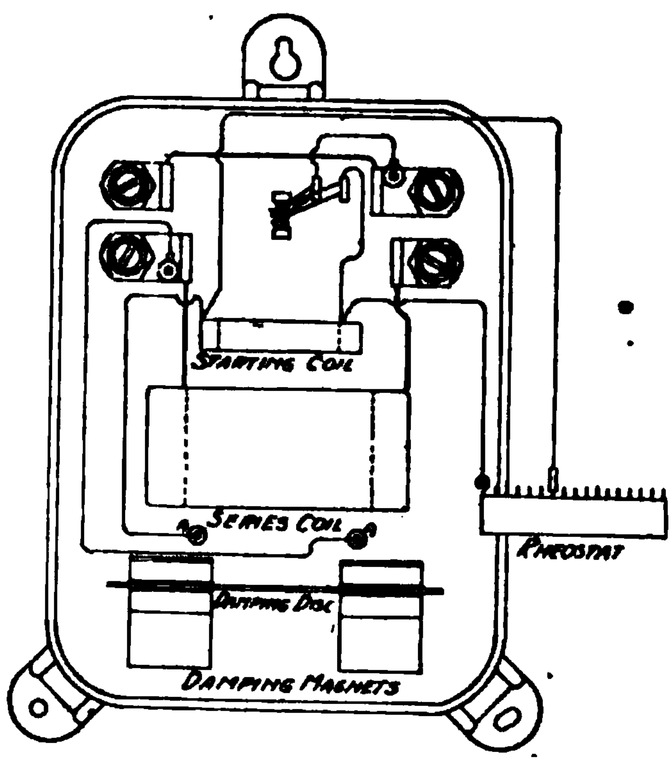


DIAGRAM OF INTERNAL WIRING OF TYPE D METERS
2 WIRE 500 VOLTS
5 TO 75 AMPERES INC.

WIRES A-A CONNECT TO RESISTANCE ON THE BACK
RESISTANCE IS SIX SPOOLS IN SERIES

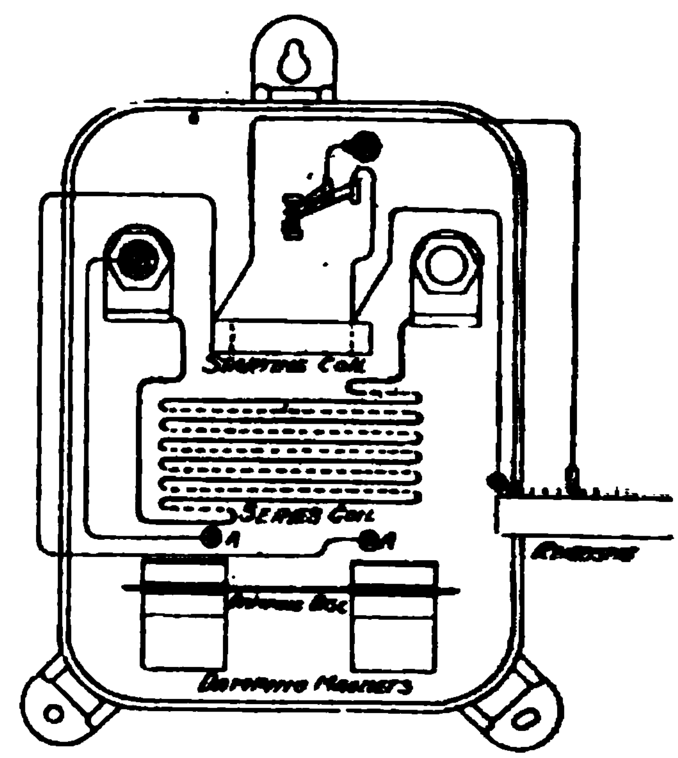


DIAGRAM OF INTERNAL WIRING OF TYPE D METERS
2 WIRE 500 VOLTS
100 TO 300 AMPERES INC.

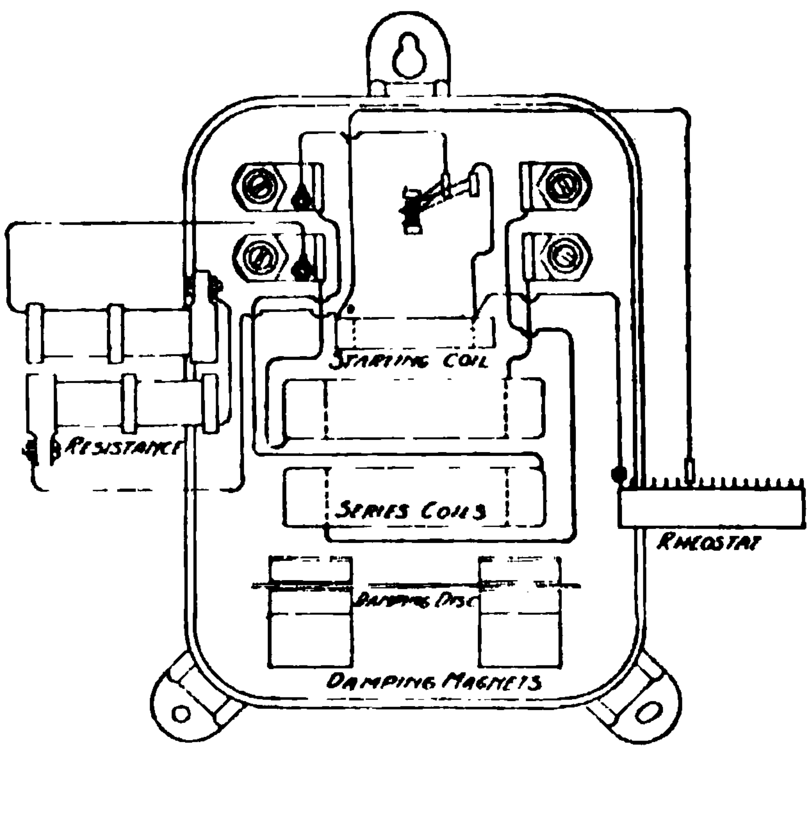


DIAGRAM OF INTERNAL WIRING OF TYPE D METERS
3 WIRE 200 VOLTS
5 TO 75 AMPERES INC.

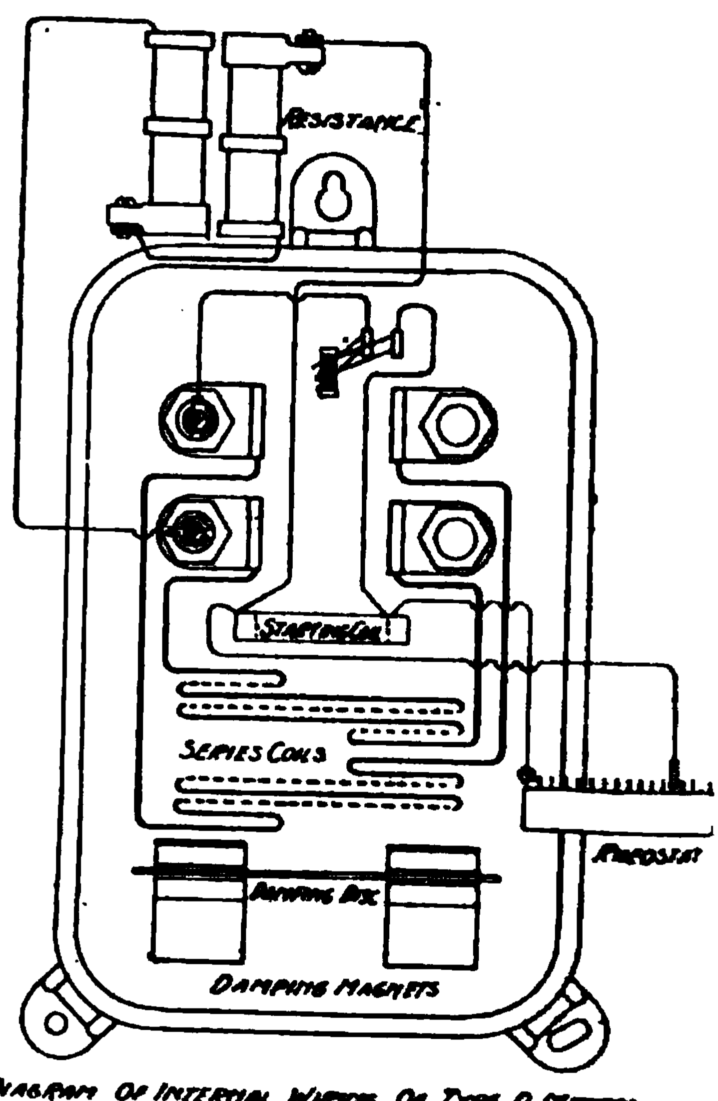
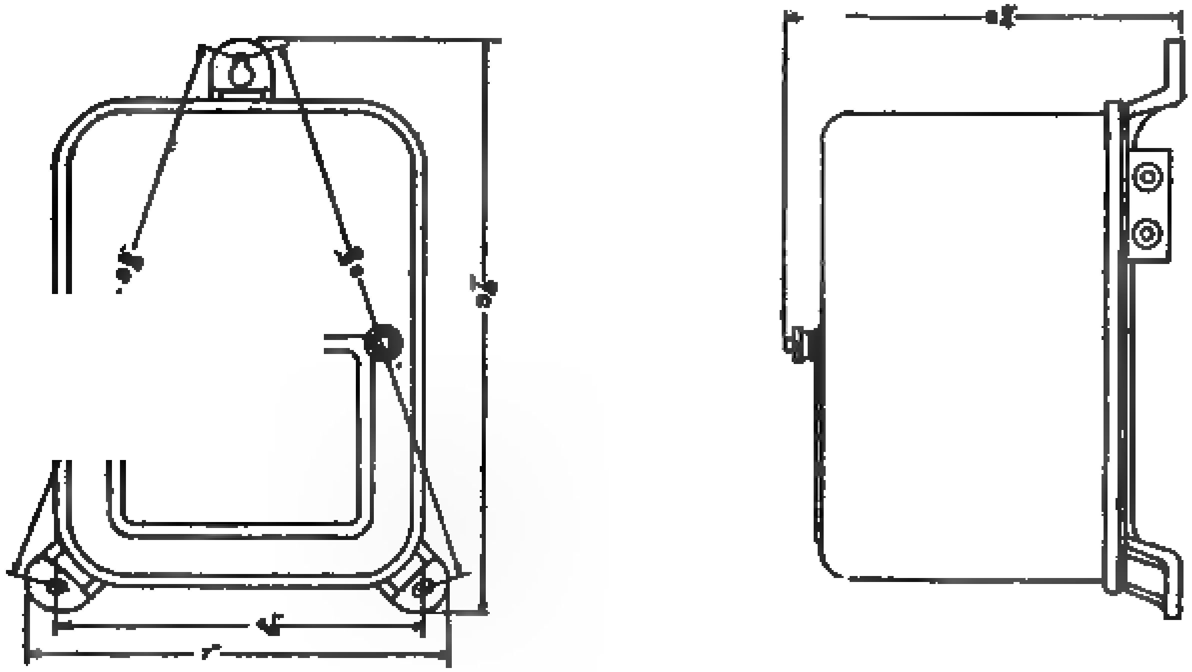


DIAGRAM OF INTERNAL WIRING OF TYPE D METERS
3 WIRE 200 VOLTS
100 TO 300 AMPERES INC.

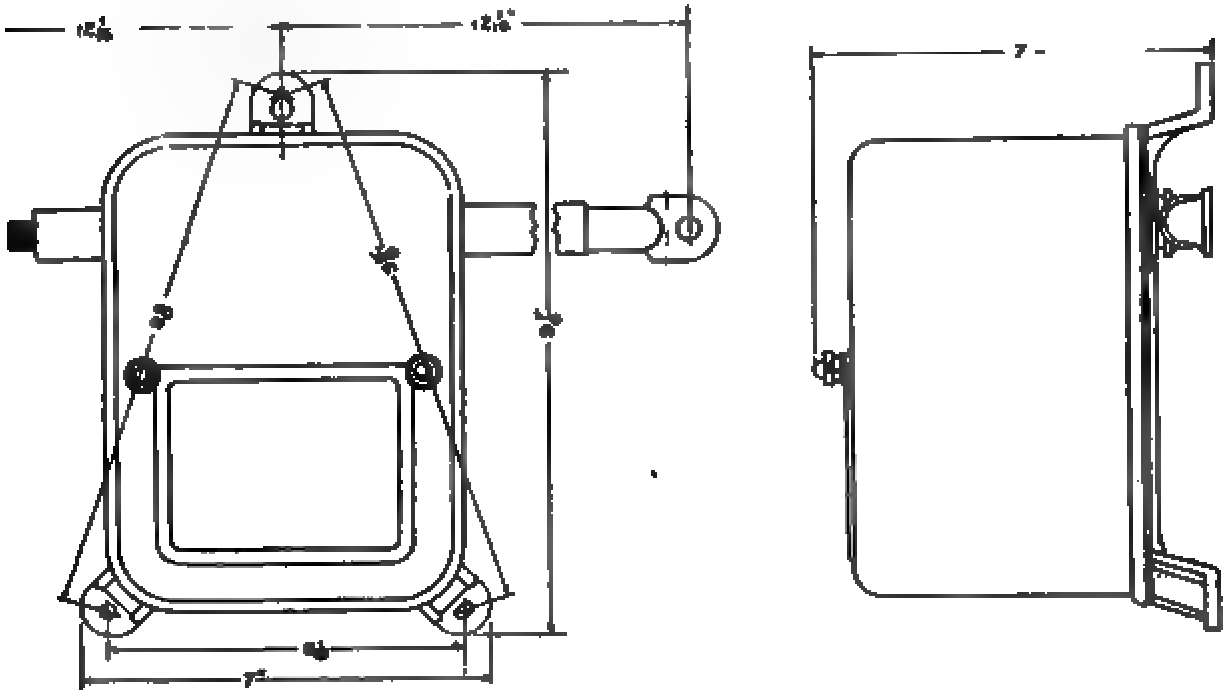
FIG. 684.—Internal Connections of Columbia, Type D, Continuous Current Watt-hour Meters

External Dimension Diagrams



OVERALL DIMENSIONS FOR TYPE D METER
5 TO 75 AMPERE, INCLUSIVE

Fig. 685.—External Dimensions of Columbia, Type D, Watt-hour Meters.



OVERALL DIMENSIONS FOR TYPE D METER
100-150-200 & 300 AMPERE,

Fig. 686.—External Dimensions of Columbia, Type D, Watt-hour Meters.

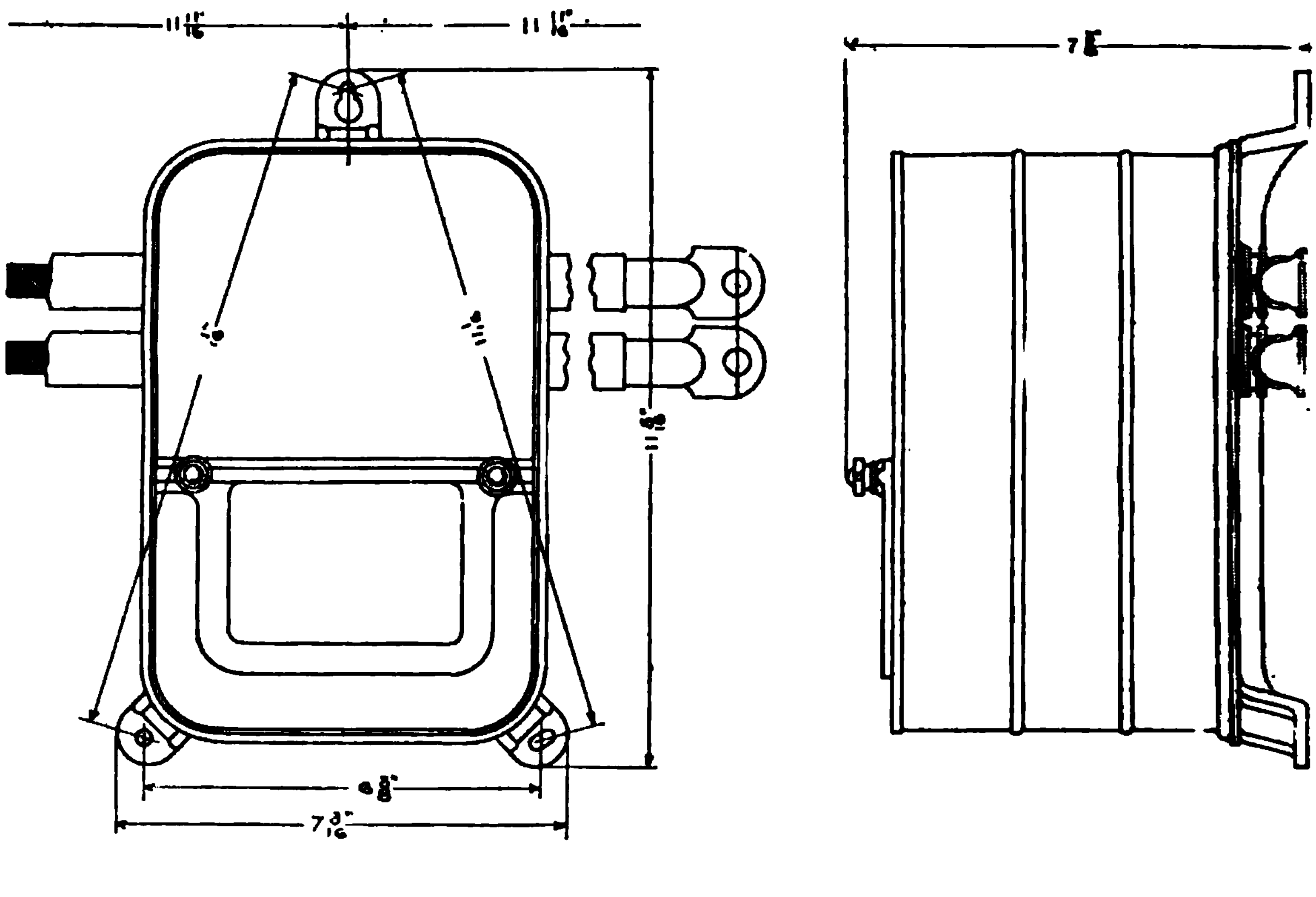


Fig. 687.—External Dimensions of Columbia, Type D, Watt-hour Meters.

Columbia Alternating Current Watt-Hour Meters

The **Columbia Type C alternating current watt-hour meters** are of the induction type, and accordingly operate on the induction motor principle—that is to say, all windings are stationary and the apparatus is operative through currents which are set up in the moving member by induction, thus obviating all commutators, collector rings or their equivalent (Fig. 688).

To induce in the rotatable disk the currents just referred to, the Columbia watt-hour meter utilizes a pair of fine wire-wound coils which

Fig. 688.—External View of Columbia, Type CI, Induction Watt-hour Meter.

Fig. 689.—Potential Element.

are connected across the supply line. Each of these coils, as is shown in Fig. 689, is wound on a laminated sheet steel core which forms a small slot at the bottom. The alternating flux which is set up by the alternating current through this potential winding passes wholly through this laminated path except that where it is interrupted by the cross slot there is naturally a leakage of some of the flux below the slot edge. As is shown in Fig. 690, the lower face of the rectangle, which is the one that is cut through, is placed parallel to and just above the aluminum disk face and the leakage magnetic flux must then pass through the latter. In so doing, it sets up the desired eddy currents, these flowing in the body of the disk. While but a small percentage of the total flux is utilized in this manner the currents in the disk are very powerful because of

the extremely low resistance of their path. The action is regarded as efficient because the fact that the winding is on a closed iron core means that the current which the coils draw from the line is an almost wattless one. For example, in the standard 100 volt size, the two potential coils together draw less than 1½ watts. Two of these potential circuit elements are in each meter for the sake of symmetry and efficiency.

Each of the potential circuit elements above referred to has co-acting with it a series element. This takes the form of a short coil wound

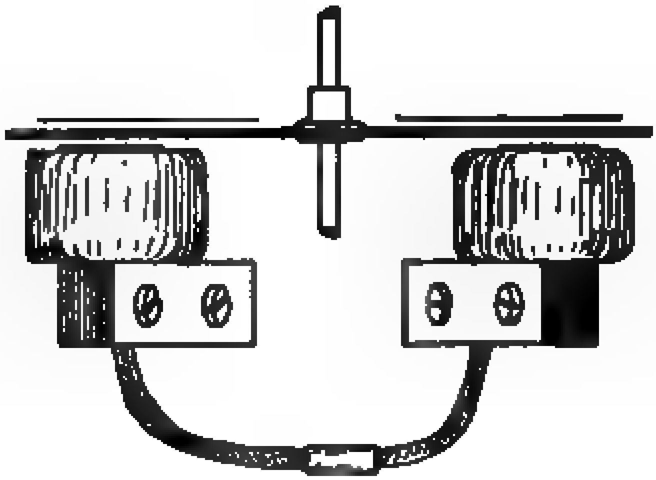


FIG. 600.—Motor Element.

with heavy wire capable of carrying the entire current with which the meter may be loaded. The said coil is mounted on a short laminated core which differs from the core for the potential circuit spools in that it is not closed on itself, but instead presents an exposed end to the aluminum disk. An alternating magnetic field is obviously set up by the current through the series spools, and upon this field the currents induced in the disk by the potential windings evidently react.

It will, of course, be understood that this description of the way in which the watt hour meter works must not be taken too literally; for example, the alternating flux set up by the series windings evidently has just as much of a tendency to induce currents in the aluminum disk

as the similar flux from the potential windings and the actual net result is that the meter has the rotating magnetic field characteristic of interacting currents which are displaced in phase. The explanation will, however, serve for illustrative purposes.

The position of the series excited magnets below the disk is somewhat displaced relative to that of the potential element above, so that the series-induced currents are reacted upon in the potential-circuit field and the potential-circuit induced currents in the series field, this disposition assisting in giving a high torque.

The arrangement of the series coil is likewise shown in the illustration of Fig. 690, above named.

As long as there is some difference in phase between the alternating magnetic impulses sent out by the potential and the series winding circuits, an induction meter will rotate and can be calibrated to be correct on a load having any given power-factor. If, however, the watt-hour meter is to be correct for all power-factors, the difference in phase between the said magnetic impulses must be 90 degrees on a non-inductive load. The fact that the potential circuit is very highly inductive by reason of its being wound on a closed iron circuit core and that the series winding carries a current in phase with the line current because it is that current, of itself nearly attains the desired end in that the phase difference between the two is thus nearly 90 degrees. It is not exactly 90 degrees, however, and to increase the angle to that value necessitates either a further lagging of the phase of the magnetic impulses due to the potential windings or an advancing of the phase of the magnetic impulses due to the series windings. The latter method is employed. It is done by shunting the series spools with another circuit which is wound on a closed path iron core, the reaction of which on the circuit in which the series coils are connected advances the relative time of occurrence of the series magnetic impulses in the desired direction. The extent of this advancing and consequently the adjustment of an exact 90 degree difference between the series and potential fluxes is accomplished by means of a resistance in the series coil circuits. This adjustably controls the relative flow through the two branches. The said resistance is illustrated in the Fig. 690 just referred to and takes the form of a loop of resistance wire bent into an elongated U shape and with a short circuiting clamp which can be slid along it to vary the amount of the wire which is actively in circuit.

There being **two potential elements** per meter, there evidently are two series ones as well, so that they may properly interact. In a two-wire watt-hour meter these two series elements are connected in

series, whereas in a three-wire meter each is connected in one side of the line.

The **moving element** consists of a disk of aluminum mounted on a shaft which has a pivot at each end and which carries a short worm which transmits the revolutions to the revolution counter. The disk has set up therein the turning forces which are above described and the edge opposite to this point of application of motive power is used for braking purposes by having it pass between the jaws of conventional meter damper magnets of tungsten steel, permanently magnetized.

The **light load speed adjustment** consists of the specially shaped soft iron punching shown in place above the laminated core of the potential element in Fig. 689. By means of the knurled head screw which is likewise there illustrated, this punching may be pushed backward, or forward, micrometerwise, thus giving a variable distortion to the potential circuit flux acting on the disk and so effecting the desired end. When advanced in the direction of rotation of the disk, the light load compensation is increased and it is decreased when the punching is oppositely moved.

The **full load speed adjustment** is accomplished by means of a light iron bridge piece which can be slid back and forth just as the light load compensator above named is handled. When so moved the bridging piece diverts a greater or less part of the flux from the permanent magnets which would otherwise pass through the disk and in that way it regulates the damping effect.

The **inductive load adjustment,** as before stated, takes the form of a heavy clamp which when slid along a loop of resistance wire varies the relative amounts of current which flow through the main series coils and through the inductive windings of the compensator coils. It is, like the light load and full load speed adjusters, structurally independent of the rest of the meter and has a wide range and at the same time is capable of close graduation.

The general conditions which will cause this type of watt-hour meter to run fast are aging of the magnets, or carelessness resulting in not tightening the full load adjustment sufficiently to hold it in place.

The general condition which will cause these alternating current watt-hour meters to run slow is the development of friction caused by defective jewels, pivots, dirty upper bearings, or bent upper pivots.

In accordance with standard practice the rotations of the shaft of the Columbia watt-hour meter are transmitted to the registering train through a worm on the shaft which drives an appropriately located

worm wheel. Instead of a solid and inflexible connection between the worm wheel and the gear train, an offset of an arm forwardly projecting from the worm wheel shaft engages with the offset of a similar arm on the train shaft which faces it and so provides for flexibility of drive. If it is at any time desired to remove the train, this can be done by slacking off two screws without disturbing the alignment of the worm and its worm wheel, and without necessitating any particular care or mechanical skill on reassembling.

FIG. 691.—Internal View of Columbia, Type CI, Induction Watt-hour Meter

The dial faces, which are regularly supplied, are those shown by the illustration in Fig. 691, that is, they are of white porcelain with dials printed thereon and hands rotating over these as in a gas meter.

For those who prefer it, a cyclometer register can be furnished, in which the results are shown directly by numerals instead of indirectly by the position of different dial hands relative to their dials. One of them is shown by the accompanying illustration, Fig. 680.

This watt-hour meter is supplied in a drawn steel base member and covered with a pressed aluminum cap in which there is a large clear glass window through which the dials and the rotating disk may be observed. The base has riveted thereto three lugs, the upper one

being central and the two others at the lower corners. The finish is all black enamel.

Tables in Chapter XV give the watt-hour gear ratios, constants and test formulas for this type of meter and the following tabulation gives additional information.

Speed at full load	30 rev. per min.
Torque at full load	80 mm-g. at 500 watts (full load)
Weight of moving element	30 g.
Ratio of torque to weight	2.66
Volts drop in series coil at full load	0.1, at 5 amperes.
Watt loss in series coil at full load	0.5
Watt loss in potential circuit	1.5
Power-factor of potential circuit	0.7
Temperature coefficient per degree C.	0.1%
Continuous overload capacity	1.5 times rated capacity.

Amperes of Meter Capacity	Diameter of Holes in Terminal Blocks (in Inches) Wire Hole	Ins. Hole	Ampere Turns 60 and 133 Cycle 2-Wire	3-Wire	25 Cycle 2-Wire
5	3/16	3/8	300	300	500
10	3/16	3/8	300	320	500
15	3/16	3/8	300	360	450
25	3/16	3/8	300	300	500
50	5/16	5/8	300	300	
75	3/8	5/8	300	300	

This meter is manufactured in sizes ranging from 2½ amperes to 150 amperes, inclusive, for 100 volt, 200 volt and 500 volt polyphase meters, and from 2½ to 300 amperes, inclusive, for 100 volt and 200 volt, two-wire, and 200 volt, three-wire, single-phase meters.

This meter was produced in January, 1911.

The internal connections for the Columbia, induction watt-hour meters are given in Fig. 692, and the external dimensions in Fig. 693

Internal Connection Diagrams

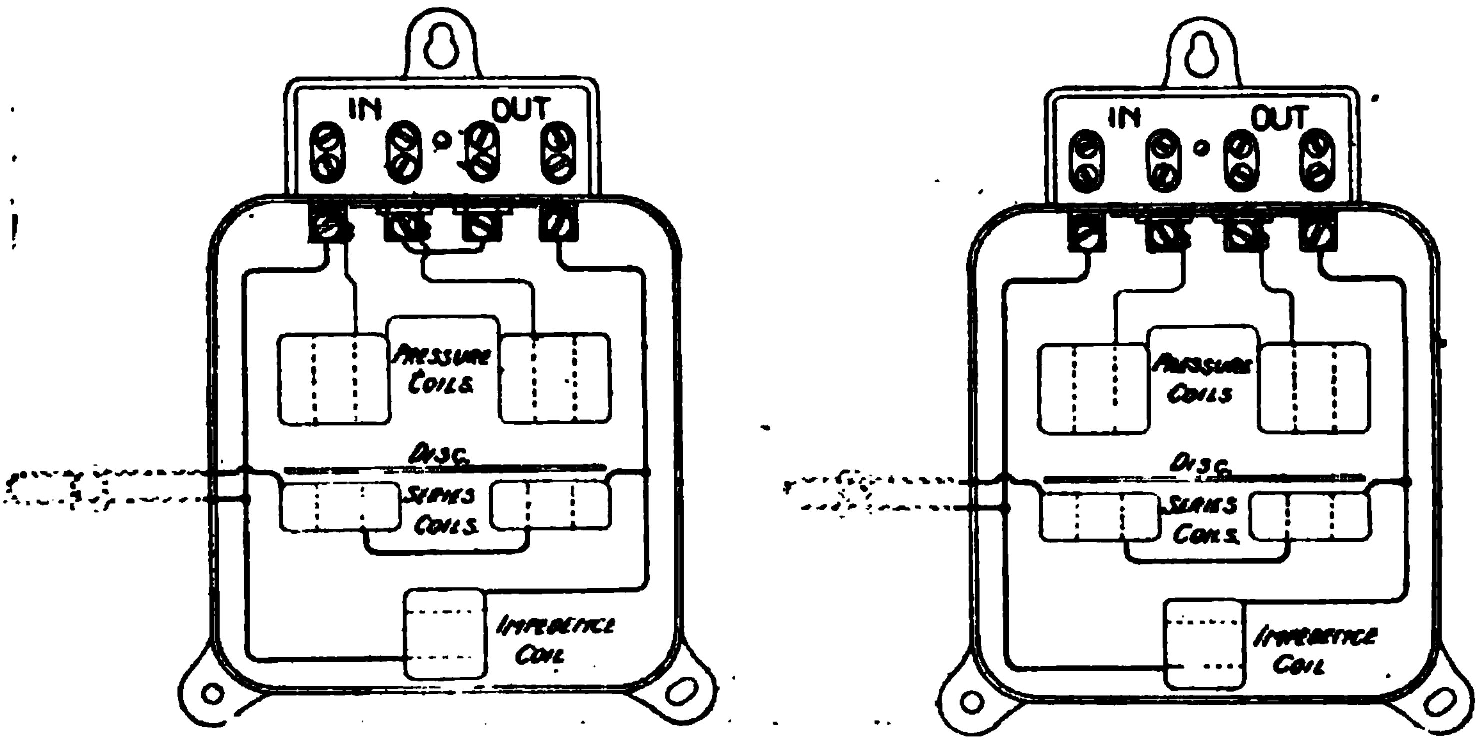
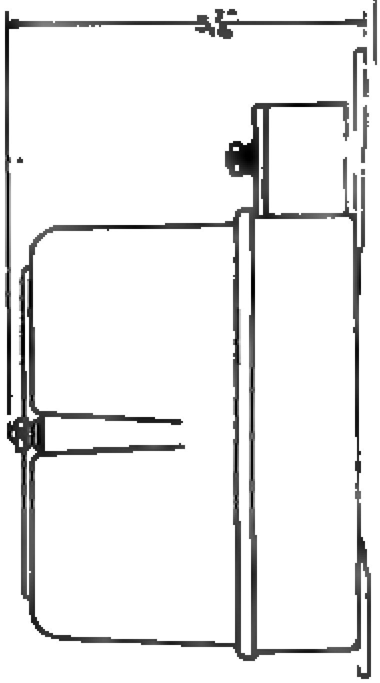


Diagram of Internal Wiring of Type CI Meters
2 Wire 0-500 Volts
5 to 25 Amp Inc.

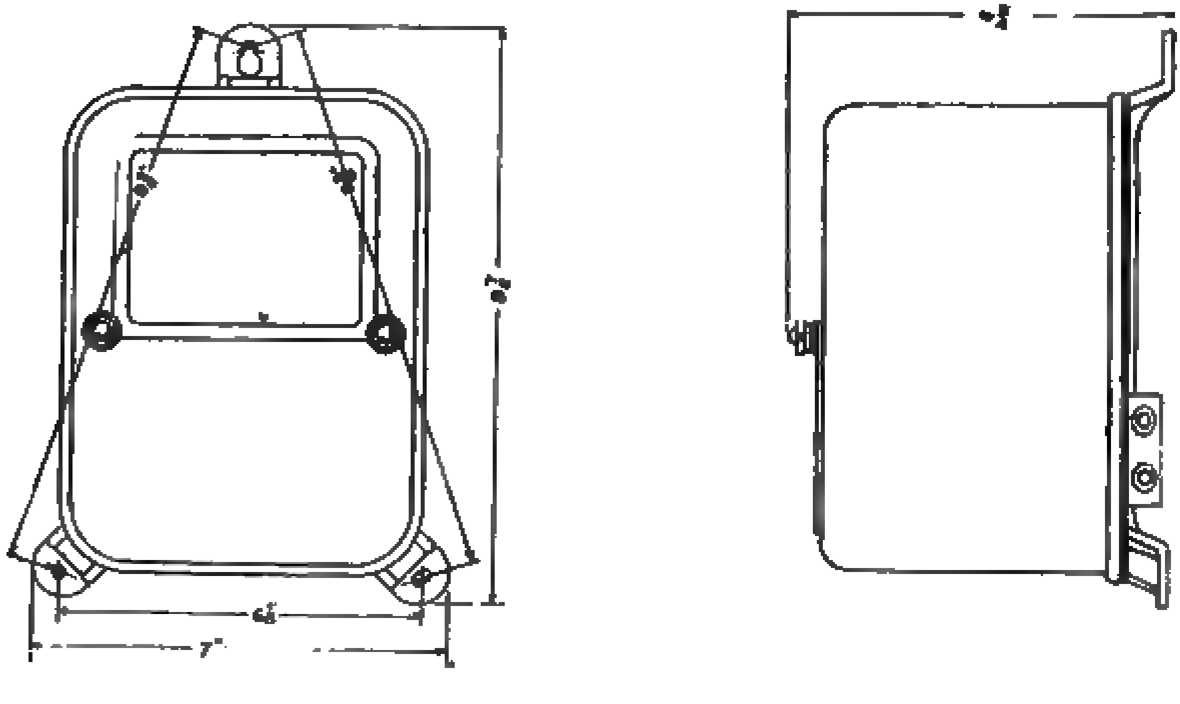
Diagram of Internal Wiring of Type CI Meters
2 and 3 Wire 0-500 Volts
100 Amp & Above.

Fig. 692.—Internal Connections for Columbia, Type CI, Induction Watt-hour Meters.

External Dimension Diagrams



Overall Dimensions For Type CI Meter
2½ to 15 Amp Inclusive, 100 to 200 Volt, 3 Wire; 2½ to 25 Amp Inclusive, 100-200 Volt, 2 Wire



Overall Dimensions for Type CI Form D Meter
25-50-75 Ampere, 3 Wire; 50-75 Ampere 2 Wire

Fig. 693.—External Dimensions of Columbia. Type CI, Induction Watt-hour Meters.

CHAPTER XVII

MAXIMUM LOAD INDICATORS

CHAPTER XVII

MAXIMUM LOAD INDICATORS

The production of electricity differs from that of other commodities in that the supply company must manufacture its product only as it is required, since it cannot be commercially stored. The capacities of the company's plant and distributing system consequently will be determined by the **maximum demand** which will be made upon them at any one time.

The cost of supplying electrical energy from a central station may be separated into two clearly defined groups:

First—The cost of getting ready to supply and distribute energy.

Second—The cost of continuing the actual supply of energy.

In order to proportion the charges to different consumers according to the cost of supplying them under both of these divisions, differential systems of rates have been quite generally adopted, under which it is necessary to measure, in addition to the amount of electrical energy supplied, **the maximum amount used** at any one time, in order to obtain the equivalent rate of supply, or the load factor.

Numerous expedients have been adopted for **fixing a consumer's maximum load,** such as basing it on a percentage of the connected load, on the floor area of the space illuminated, or, in residences, on the number of rooms lighted. While these have been quite satisfactory for certain classes of small consumers, an actual measurement of the individual maxima has been found desirable for larger consumers.

A **maximum load (demand) indicator** is an instrument which leaves a record of the maximum load, which has existed in the circuit. Such meters are designed not to indicate instantaneous values of load, but rather to record maximum values of load continuing for a definite and predetermined time.

There are several types of instruments which may be used for this purpose:

Ampere Demand Indicators.

Watt Demand Indicators:

Printing attachments to Watt-hour Meters.

Graphic Recording Instruments.

An important consideration in connection with these instruments is the time lag or interval during which the maximum is averaged. A description of several devices obtainable in this country follows.

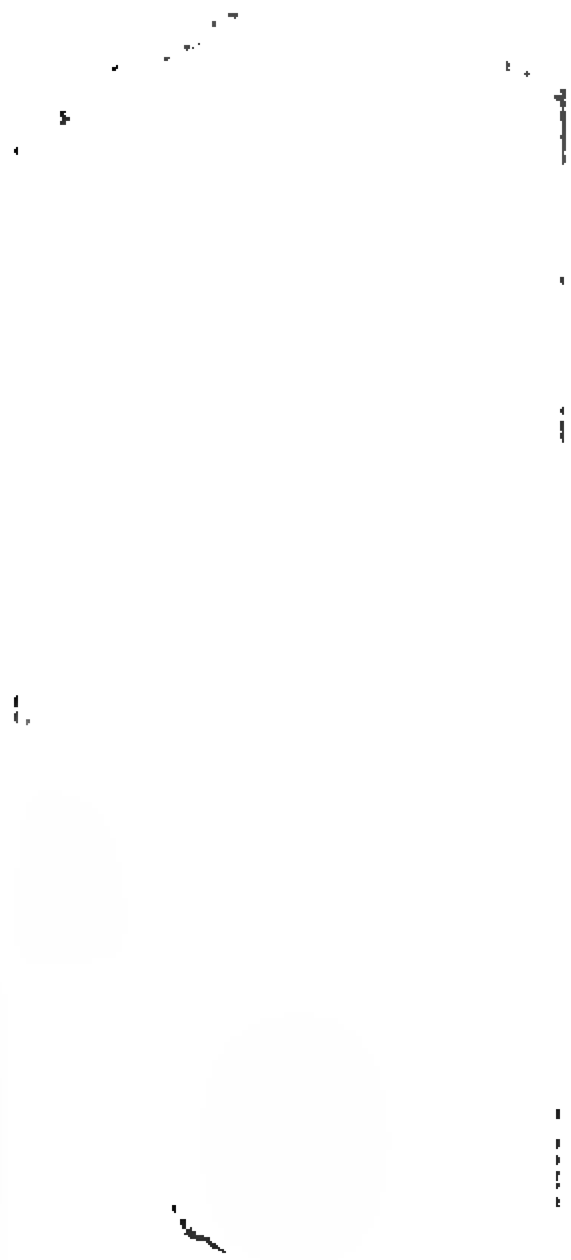


FIG. 694 — Wright Demand Indicator

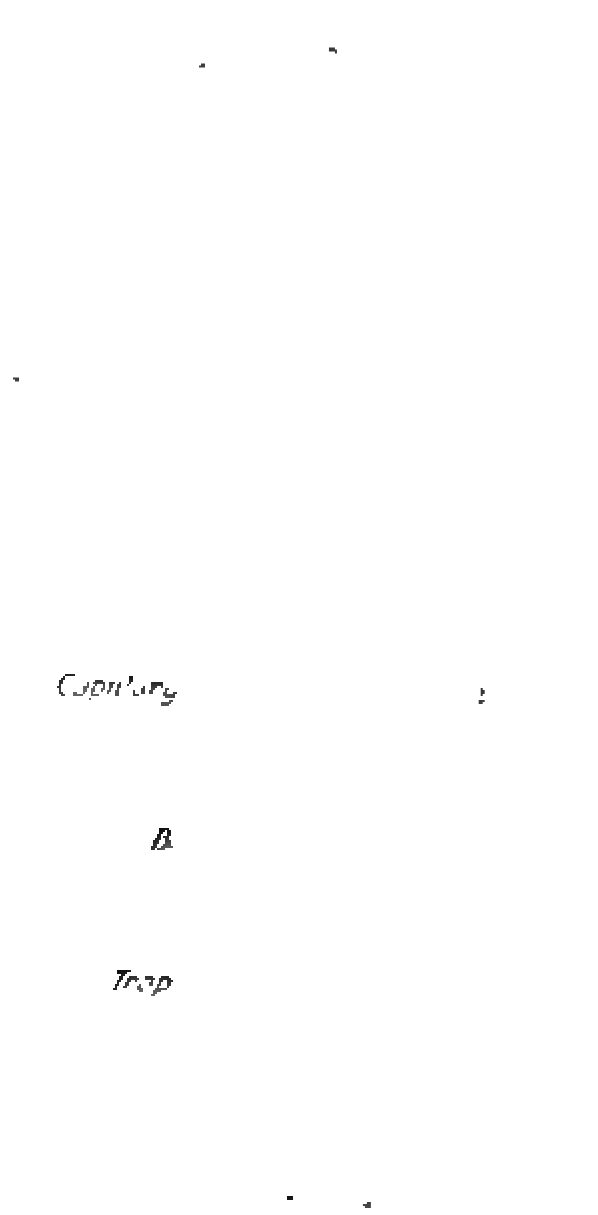


FIG. 695 — Registering Element of Wright Demand Indicator.

The Wright Demand Indicator (Fig 694) is a device for registering the maximum ampere demand of appreciable duration in any electrical circuit. It may be used on either continuous or alternating

current circuits, and records the maximum current which has passed through it at any time since it was last set.

It is purposely designed to be slow acting. If the maximum load lasts only four minutes, the indicator will record approximately 90 per cent of the maximum. If the load lasts ten minutes, approximately 97 per cent is recorded, and if the load continues about 40 minutes, the full 100 per cent is recorded. Momentary overloads, like the starting current in motors and arc lamps, or short circuits, are not recorded.

The working parts are enclosed in a cast iron case which can be securely sealed against tampering and which is fitted with a glass front so that the indicator can be read without opening the hinged cover.

A liquid is hermetically sealed in a glass vessel consisting of two bulbs (Fig. 695) connected by a "U" tube, and a central tube called the "Index" tube connected to the upper end (Fig. 695) of the right-hand side of the "U." Around the left-hand or heating bulb, is placed a band of resistance metal through which is passed the current to be measured, or a definite shunted portion of it. The heating effect of the current increases the temperature of the left-hand bulb, causing the air to expand which forces the liquid up the right-hand side of the "U" tube and into the "index" tube, where it remains until the indicator is reset. The height of the liquid in the "index" tube as shown by the scale indicates the maximum current which has passed through the indicator. The liquid in the "U" tube is concentrated sulphuric acid in such an amount and so adjusted that when the indicator is cold and set ready to begin to operate, the level of the liquid is just at the point of overflow into the "index" tube. Sulphuric acid is used because it "wets" the glass, is very heavy, flows readily, is hygroscopic, and expands comparatively little with rise of temperature.

It is the difference in temperature of the air in the two bulbs which causes the flow of the liquid. Any change in external temperature causes equal air expansion in both bulbs, and therefore does not affect the reading.

The glass tube is mounted on a suitable hinged support, enabling the indicator to be reset by raising the tube and allowing the liquid to return to its original position in the "U" tube. To prevent accidental transfer of air from one bulb to another when the indicator is reset each arm of the tube is constricted at one point to a capillary and also traps are provided.

The terminals which are located in the top of the case, are made in the form of a horizontal friction hinge holding the tube support. This friction hinge automatically retains the tube in the inverted position during the period of resetting.

The heating bands are made of a high resistance metal with zero temperature coefficient and are non-inductive. In capacities as high as 25 amperes, the entire current is passed through the heating bands. In indicators of larger capacity, the heating bands are connected either to internal or external shunts. The heating bands are so designed that they will clamp firmly about the heating bulb, irrespective of any variations in bulb dimensions. Inasmuch as the heating effect increases as the square of the current, these indicators can be made for two-wire circuits only, and on a three-wire circuit, one must be installed on each side of the circuit (Fig. 696).

The scale reads directly in amperes, and may have, in addition, a kilowatt-hour scale for a definite potential and interval (Fig. 370). The lowest scale reading is 20 per cent of the rated capacity of the indicator which has been found to be practical for commercial applications.

Wright Demand Indicators of all capacities from 5 to 150 amperes inclusive may be used interchangeably on continuous or alternating current circuits of any frequency. Indicators of 200 amperes capacity, and over, are furnished with shunts for continuous current service, and with current transformers for alternating current circuits.

The shunts are, in all cases, internal except in connection with indicators of 800 amperes and over.

Current transformers must be used in all cases on alternating current circuits where the potential exceeds 600 volts.

The Wright Demand Indicator has a large overload capacity so that it may be safely operated on loads of double its rated capacity without injury. It should be remembered, however, when operating at its rated current the index tube is filled in 40 minutes, hence an overload may quickly fill the tube and render an accurate record impossible.

This device is manufactured by the General Electric Company.

External dimensions are given in Figs. 697 and 698.

The **Polyphase Maximum Watt Demand Indicator** is suitable for recording the maximum load on alternating current circuits, irrespective of power-factor and voltage fluctuations (Fig. 699).

The Type *W* device is, in its essential elements, a Type *D3*, General Electric polyphase watt-hour meter with both electrical elements acting upon the top disk, and a very strong damping system acting upon the lower disk to provide the necessary time lag. The rotating element is controlled and opposed by three phosphor-bronze springs connected in series. These springs permit the moving element to make three complete revolutions while the indicating pointer makes a single revolution by means of a 3:1 ratio of gearing.

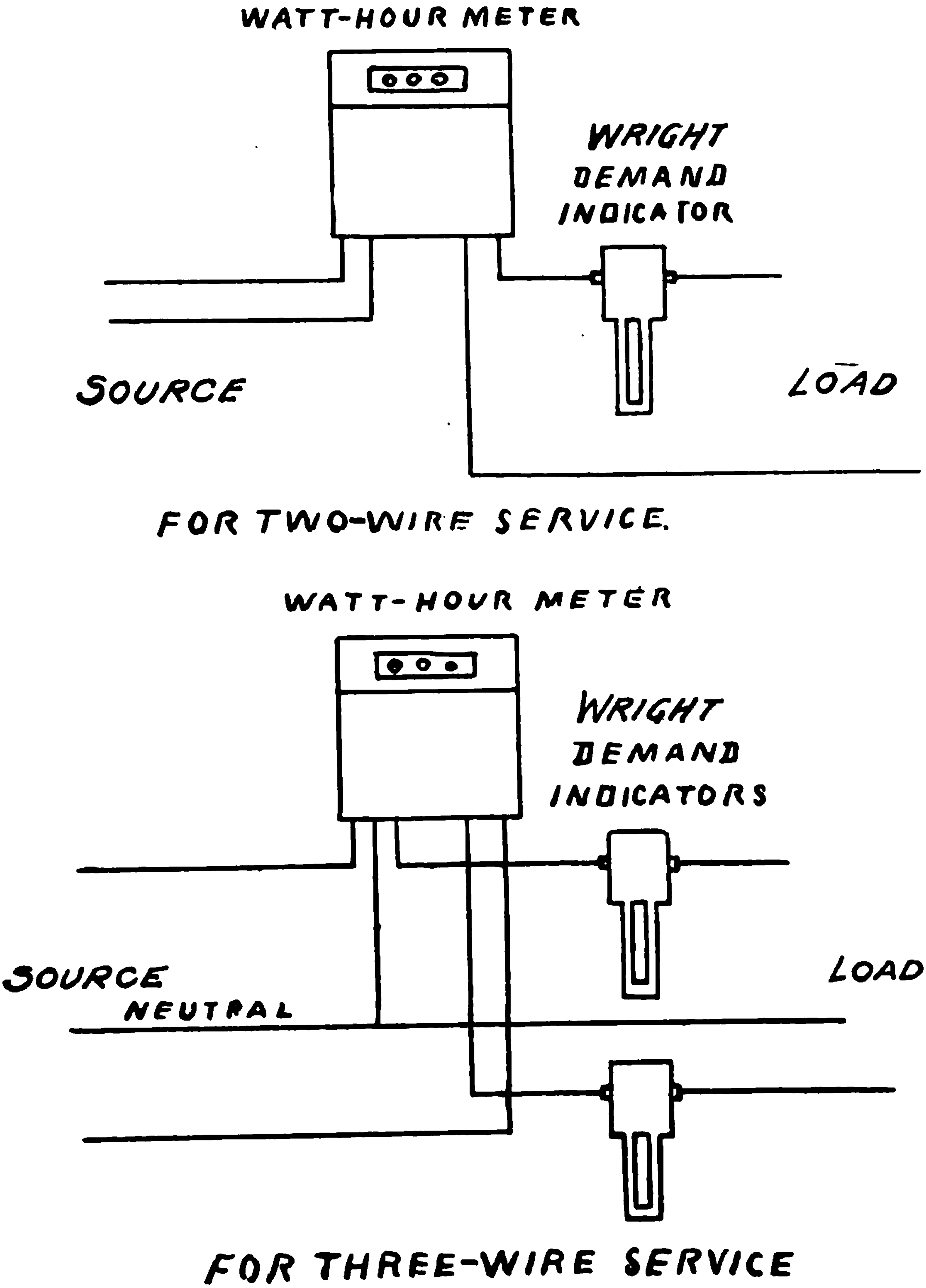


FIG. 696.—Connection Diagram for Wright Demand Indicators.

In place of a register, there is provided a single graduated dial and two pointers, one of which indicates the energy passing through the indicator at any time, subject to a correction due to the time lag. Th

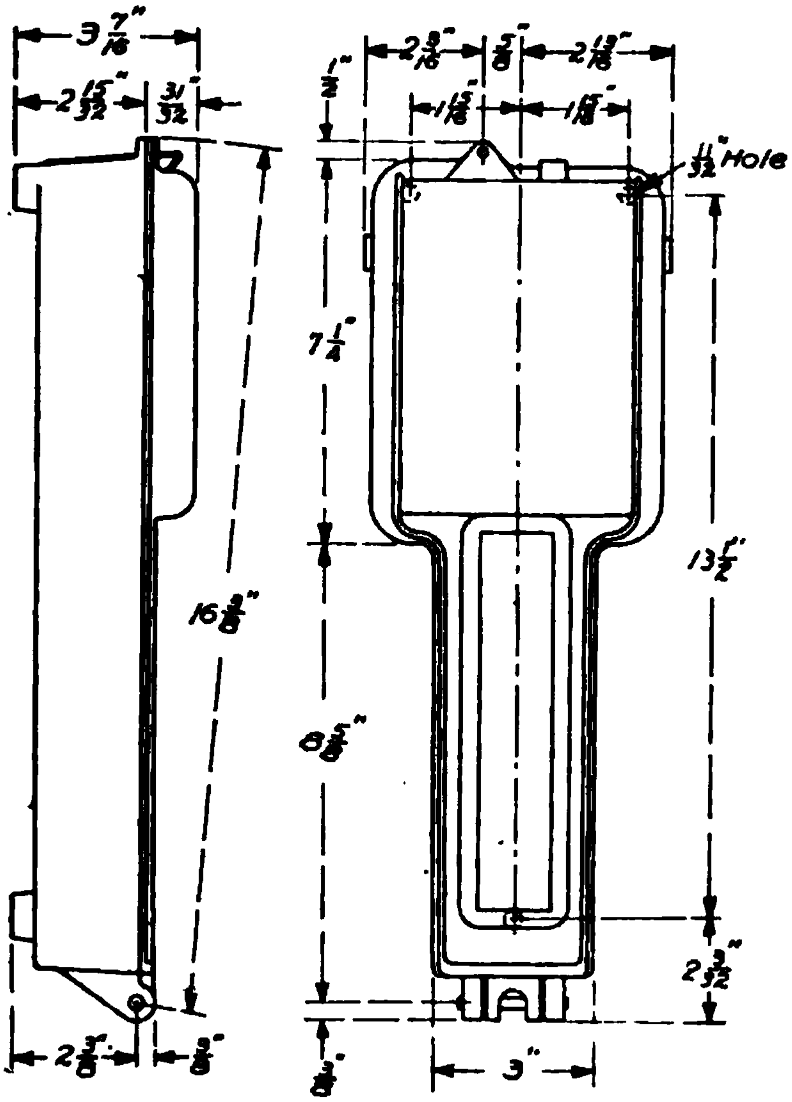


FIG. 697.—External Dimensions of Wright Demand Indicators for Continuous or Alternating Current, 5 to 150 Amperes Capacity.

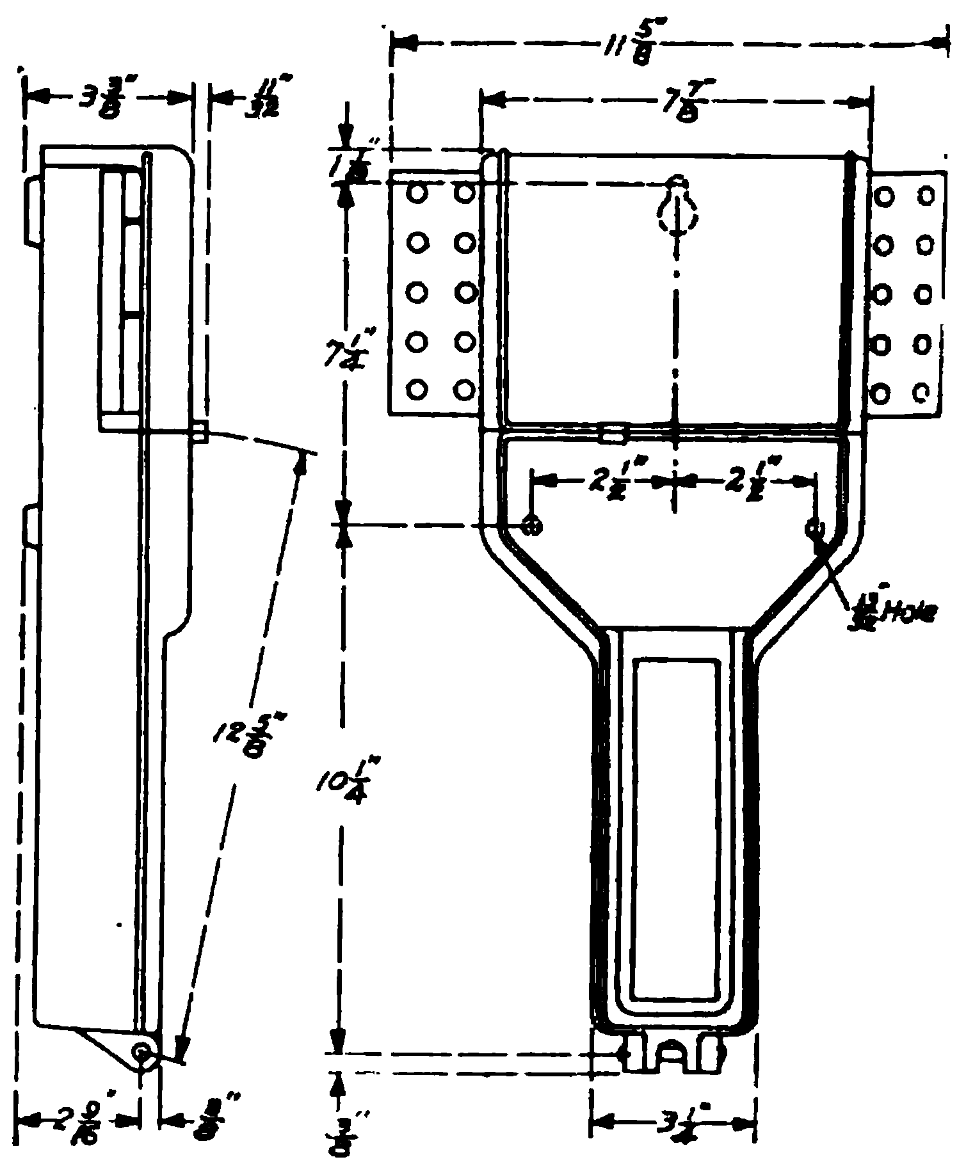


FIG. 698.—External Dimensions of Wright Demand Indicators for Continuous Current only, 200 to 600 Amperes Capacity.

other pointer is driven by the first and is left at the maximum position reached by it, being held in place by a ratchet. This second pointer indicates, therefore, the maximum energy which has passed through the device since it was last set. A thumb nut, which may be sealed to prevent tampering by unauthorized persons, is used to reset the maximum demand pointer to the zero position. The torque is proportional to the energy passing through the device. This, in connection with the spring control, gives a uniformly divided scale.

The Polyphase Maximum Watt Demand Indicator is rated by defining the time lag as the interval of time taken to record 90 per cent of any change in load, that is, if the rated time lag is five minutes, the meter

FIG. 699.—General Electric, Polyphase, Maximum Watt Demand Indicator.

would indicate 90 per cent of the load which was impressed on it for five consecutive minutes, e. g., if 100 kw. were impressed, it would indicate 90 kw. in five minutes. The reason for defining the time lag as shown above is that, between 90 and 100 per cent, the movement is very slow compared with the speed from zero to 90 per cent. The length of time for the pointer to reach its maximum position is governed by the torque of the motor elements and the strength of the damping magnets. By adjusting these parts, it is possible to get a time lag at 90 per cent of full scale, varying from one minute to five minutes. It is also possible by adjusting the dampening magnets to change the time lag of an indicator having a definite rated time lag by from ten to fifteen per cent.

The Type *W* Polyphase Maximum Demand Indicators are made self-contained in capacities of from 25 to 150 amperes, 220 to 650 volt

except four-wire, three-phase indicators which are not made self-contained in current capacities above 25 amperes. With instruments of greater capacity, current and potential transformers are used.

This indicator is side-connected and is furnished with an all-metal cover in black japan. It is manufactured by the General Electric Company.

The **Printometer** is an instrument for use with watt-hour meters, printing in plain figures on a continuous paper tape the consumption during every interval as registered on the meter with which it is used. It prints the time in a column parallel to that showing the consumption, thus giving also the time of day when the energy was consumed.

The device consists primarily of a set of cyclometer type wheels, which are electrically interdriven by the armature of a solenoid, energized through the medium of an electric contact placed on the register of any meter. These wheels are moved forward at a rate which is proportional to that of the flow of energy through the watt-hour meter, and will, therefore, at any instant give an indication which is equivalent to the reading of the register. Through the agency of a rubber platen and copying ribbon this reading is printed on a paper tape. When the platen is actuated by an electric solenoid, whose circuit is closed at regularly recurring intervals by means of a contact making clock, there is obtained a tape which has printed upon it a reading equivalent to the reading of the watt-hour meter at the end of each interval.

The device is not in any sense of the word an integrating meter, but is an automatic recording mechanism which is connected to any integrating type of meter.

The particular uses of the devices are:

First—Obtaining the Maximum Demand.

Second—Determining Load Factor.

Third—Determining Diversity Factor.

Fourth—Determining the Use of Off Peak Power.

Fifth—Determining the Use of Breakdown Service.

Sixth—Complaint Work.

Seventh—Special Tests of Power Conditions.

The cut of Type *SC* Printometer shown in Fig. 700, will serve to show the various mechanical and electrical parts of the device. The cyclometer coil, shown at *A*, is energized from the line through the agency of the contact-making commutator placed on one of the spindles of the recording train of the watt-hour meter, and is actuated at a rate proportional to the energy passing through the meter. The forward motion of

the core contained within this solenoid moves forward progressively a set of three cyclometer type wheels, shown in more detail at *V*, Fig. 701. The energization of this cyclometer coil is obtained in the follow-

FIG. 700.—Printometer, Type SC.

ing manner, in order to prevent the continuous flow of current through the winding. Should the meter happen to stop while the contact on the register was closed, the coil would remain continuously across the line, and would in time be burned out. A special type of circuit is used, which

FIG. 701.—Partly Assembled Printometer, Showing Type Wheels.

causes the current to flow only a length of time necessary to allow the plunger to reach the end of its stroke. It also accomplishes the reduction of current consumption to a minimum. This is effected in the following manner: A commutator *A*, placed on the watt-hour meter registe

Fig. 702, consists of a slip ring, which has connected to it various numbers of bars, depending upon the constant used with the attachment. Three contact brushes, one bearing upon the slip ring, and the other two placed diametrically opposite each other in the path of the bars, alternately close the circuit through the cyclometer solenoid. As the armature of this solenoid is moved forward, it revolves, through a part of the revo-

Fig. 702.—Register Contact Device.

lution, a contact wheel which has alternate segments of conducting and insulating materials, the conducting segments being connected to a slip ring. This wheel also has three brushes, one being in contact with the slip ring, and the other two so arranged that one will be resting upon conducting, and the other upon insulating material, as shown in Fig. 703. This contact wheel constitutes a second series break in the circuit

Fig. 703.—Detail of Type SC Printometer.

of the cyclometer solenoid. When the contact commutator rotates into such a position that the circuit with one of the brushes is closed, the core of the solenoid will be drawn forward, at the same time rotating the ontact wheel When the armature has reached the end of its stroke, the act wheel brush which was formerly resting upon a conducting seg- , will be transferred to an insulating segment, thus breaking the

circuit and allowing the armature to return to its former position. This cycle of operations causes the circuit of the solenoid to be closed by the contact commutator and opened by the quick moving contact wheel, thus restricting all arcing of the contacts to the more rugged part of the instrument and giving an equivalent of the snap break, as shown in Fig. 703.

The printing solenoid, shown at *B*, Fig. 700, is connected to the line through a series break in the contact-making clock, and is energized for a period of approximately one-third of a second at recurring intervals, such as fifteen minutes, one half hour, or one hour. The core of this solenoid carries at its upper end a rubber platen, shown at *C*, Fig. 700, which is used to force the paper tape *D* and copying ribbon *E* against the type wheels to form the print. Upon the downward stroke of this

FIG. 704.—Side View of Type SC Printometer

core, a lever *F* is used to revolve, through one-twelfth of the circumference, a ratchet mounted on the shaft *G*, which also carries the pin wheel *H* and gear *J*. This motion is transmitted through the gear *K* to the re-wind paper drum L, which advances the paper tape approximately $\frac{5}{8}$-inch, a fresh supply being obtained from the right hand roll *M*, and at the same time a pinion mounted upon the shaft *G*, meshing with the gear *N*, advances the copying ribbon approximately $\frac{1}{32}$ inch. The pin wheel mounted upon the shaft *G* has twelve pins meshed with the star wheel *O*, which in turn controls the motion of the hour wheel, shown in more detail at *X*, Fig. 704. A pointer *P* is mounted directly on the shaft of the hour wheel, and indicates the particular number which is ready to print.

All parts of the device are mounted upon a base plate *Q*, which in turn is mounted within a cast-iron base. The glass cover *R*, held in place by

a center thumb nut *S*, and coming into contact with a felt washer *T*, protects the instrument from dust and fumes and allows inspection without removing the seal, which is passed through the thumb nut *S* and the stud which carries it.

The contact-making clock is contained within a glass cover and mounted upon a base exactly like those of the Printometer. The contact feature of the movement is entirely separated from the timing element, each one being driven by entirely separate mainsprings. Mounted upon the center spindle, Fig. 705, of the time element, this center spindle corresponding with the minute hand of the clock, is a cam, *B*, with various numbers of points, as at *C*, depending upon the particular contact inter-

FIG 705—Contact Making Clock and Details.

val; for instance, twelve for a five-minute and two for a thirty-minute interval. This cam, as it revolves, trips off, through a lever mechanism, an escapement on the spring and gearing of the contact element. At each tripping, a spindle contained within this train is allowed to revolve exactly one revolution, and is then locked in position During a part of this revolution, a short circuiting ring, *E*, makes contact with two brushes, *F* and *G*, which constitute a series break in the circuit. Before the end of the revolution, these brushes drop off of a projection of the contact ring, *H*, and break the circuit The length of duration of contact is regulated by the area of the retarding fan, *I*, contained within the instrument.

Each device, when shipped, is set for a definite time interval, and can-
be changed except by removing the cam upon the center spindle and
'acing it with one with the proper number of points. Any contact

making clock may be used upon any voltage, or current, there being no coils or other connections except the mechanical closure, and opening of the circuit. The clock furnished is an eight-day key-wind timepiece, it being necessary to wind both springs each week. It may be set forward, similar to any other timepiece without interfering in any way with the contact device.

The electrically operated switch, an auxiliary appliance, is always used when two, or more, Prinometers are to be operated simultaneously from one contact-making clock. This is nothing more or less than a relay for carrying and breaking, the larger current required by a greater number of instruments. It is furnished with a coil similar to that used for the printing mechanism of the Printometer and will be furnished for any standard voltage.

The standard voltages and currents used in these instruments are:

Voltages	Printing Coils	Cyclometer Coils
110 V., 60 cycles.................	1.5 amperes	0.3 amperes
110 V., continuous current.......	0.7 "	0.1 "
220 V., 60 cycles	1.0 "	0.1 "
18 V., Battery	5.5 "	1.0 "

A complete single installation of the device comprises:

1 Printometer,
1 contact-making clock,
1 contact device applied to watt-hour meter register (Fig. 706).

For a multiple installation of two or more attachments, the required apparatus will consists of:

2 or more Printometers,
1 contact-making clock,
1 electrically operated switch,
2 or more contact devices applied to two, or more, watt-hour meter registers (Fig. 707).

The above description applies particularly to the present form of the instrument, and a description of the previous types therefore follows:

The Type *A* Printometer, formerly known as the Chicago Printing Attachment, was designed primarily for a General Electric Company's IS-2 watt-hour meter, and was directly connected to the meter. It was produced during the period from 1908 to 1909. It contains five type wheels geared together in ratios of one to ten, the first, most rapidly moving, wheel being geared to the moving element. This instrument was con-

structed for operation at intervals of one hour and cannot be changed The paper is slowly advanced by means of a clock contained within the case, the same clock being used to close the circuit of the printing coil which makes the impression through the agency of a rubber platen and copying ribbon.

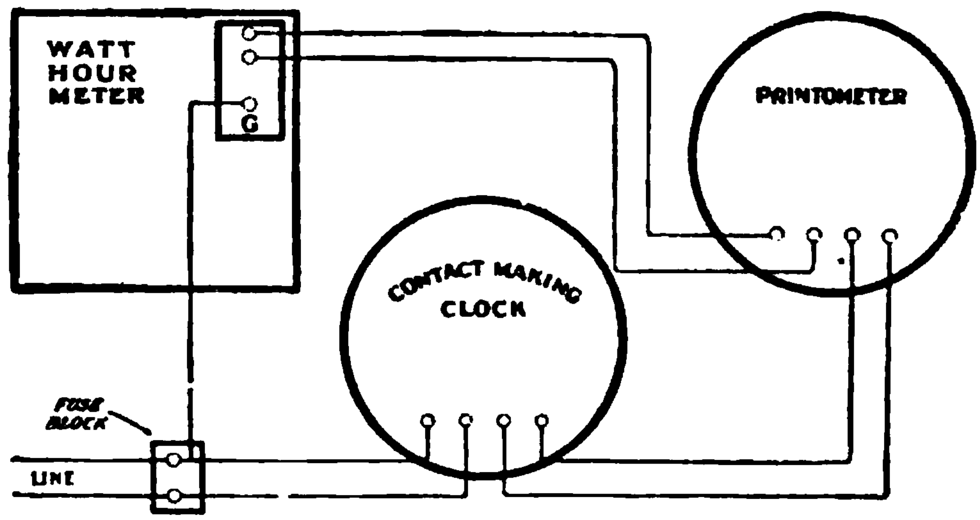


FIG. 706.—Diagram of Connections for Single Installation of Printometer.

The somewhat later form of the Type *A* device has the clock mounted in a separate case without the meter, which merely closes the circuit of the printing solenoid. Upon the downward stroke of the plunger the paper is advanced through the agency of a ratchet and pawl.

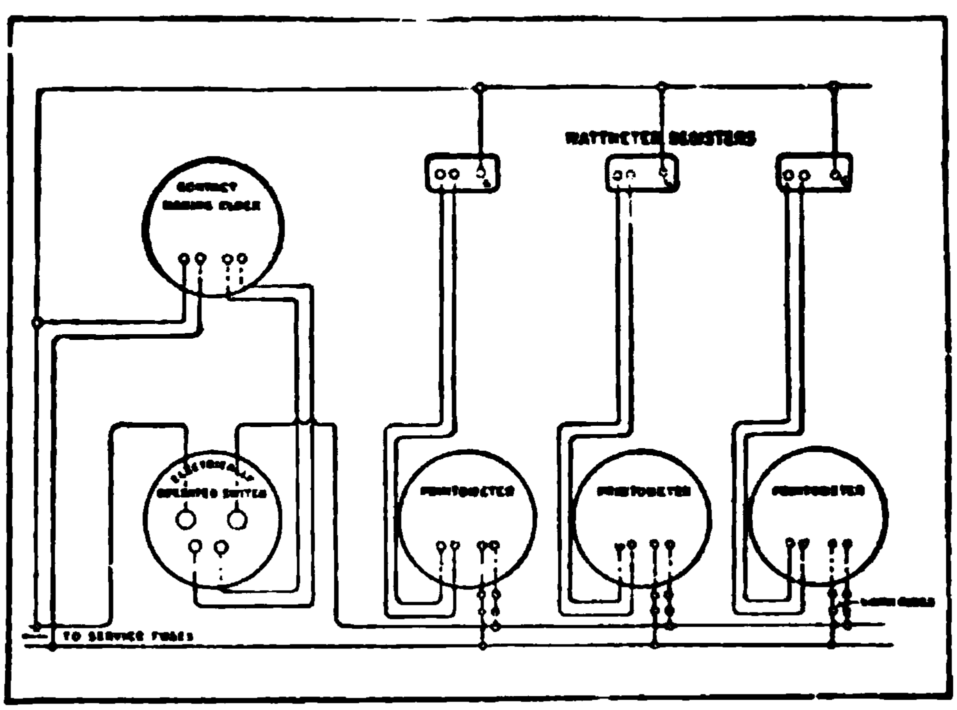


FIG. 707.—Diagram of Connections for Multiple Installation of Printometer.

The Type *B* device was designed to be used with both General Electric Company's and Fort Wayne Electric Company's watt-hour meters, and can be adjusted for various time intervals, such as five, ten, fifteen, thirty minutes, and one hour. This is accomplished by changing the contact

interval of the clock by an adjustable arrangement of pins in the pin wheel which advances the hour wheel. In all other respects it is exactly similar to the second form of Type *A*. This form of Printometer contains four type wheels and one hour wheel. This type was produced during the period from 1909 to 1910.

The Type *C* device was radically different from the former, in that the cyclometer type wheels were electrically connected to the register instead of being geared directly to the moving element of the watt-hour meter. Thus the original register was left on the meter and could be read if desired. The special form of circuit employed in the later forms of Printometers is used to energize a solenoid, the armature of which moves forward, progressively, the type wheels—thus keeping this reading of the type wheels equivalent to that of the watt-hour meter register. This device requires for its attachment no alterations in the mechanism of the watt-hour meter, and keeps intact the meter's dial face, thus allowing both visual and printed records to be taken. The connection to the Printometer is maintained through a contact commutator placed on one of the spindles of the watt-hour meter register. The Printometer is contained in a separate case, which can be mounted at any distance from the watt-hour meter with which it is connected. The contact-making clock, as in the Type *B* device, is separate from both watt-hour meter and attachment, and simply closes the circuit of the printing coil at regular intervals. An adjustable time interval arrangement, as used in the Type *B* attachment, is also employed in the Type *C*. This form of printometer contains five type wheels and one hour wheel.

The above described types are now quite obsolete and some of the later designs will now be described.

The Type *S* and Type *SC* devices are in all essential principles exactly like the former Type *C*, the only differences being in details of design and construction. These types were produced during the period from 1911 to date. The instrument is contained within a glass cover, to allow visual inspection and reading of the record without unsealing. The type wheels have been reduced in number from five to three (Fig. 708).

The difference between Type *S* and Type *SC* Printometers lies simply in the form of connections, the Type *S* being front connected and the Type *SC* being back connected, or switchboard form. Terminal and holding studs for panels from 1½ to 2½ inches thick are furnished.

The Type *P*, or portable Printometer consists of one Type *SC* attachment and one five minute interval contact making clock, mounted in an oak carrying case, and comprises a complete installation when used in conjunction with watt-hour meter registers equipped with con-

tact-making commutators. This type was produced during the period from 1911 to date (Fig. 709).

This instrument is made in two different forms, known as Type *PL* and Type *PB*, the difference being only in the source of power utilized. Type *PL* is arranged for operation directly from the line, and, by means of a compound wound coil, may be operated by 110 volts alternating current, 110 volts continuous current, and 220 volts alternating current. Type *PB* is wound for 18 volts continuous current, and should be used with a battery of twelve dry cells, which is furnished with the instru-

FIG. 708.—Printometer, Type S.   FIG 709.—Printometer, Type P, Portable.

ment This battery, under normal operation, will give satisfactory service for approximately one month's continuous running.

The Printometer is nothing more than an automatic recording mechanism which receives impressions from the watt-hour meter. In testing watt-hour meters with this attachment, therefore, the testing instructions and formulas given in Chapter VII and Chapter XVI may be applied.

There are two variables in the device and its auxiliaries which should be calibrated: first, the watt-hour meter with which the Printometer is used, and second, the constant to be used with the tape readings in order to convert them to kilowatt-hours or proper units. The calibration of the watt-hour meter should be performed with the contact making commutator in place on the register. Under normal conditions this attach-

ment will not affect the action of the watt-hour meter, since the friction introduced should be negligible, but in extreme cases, with very high speed commutators, it is possible that on 5 per cent load the watt-hour meter may run a maximum of 4 per cent slow. This should then be compensated for by the light load adjustment.

The multiplier M, is always marked upon the dial face above the dials of the watt-hour meter register which is equipped with the commutator, and checking of this value can be accomplished. An approximate check can be made by operating the watt-hour meter at full load for a given period of time, with the Printometer electrically interlocked with the watt-hour meter register. The number of kilowatt-hours which have passed through the watt-hour meter during the interval, divided by the

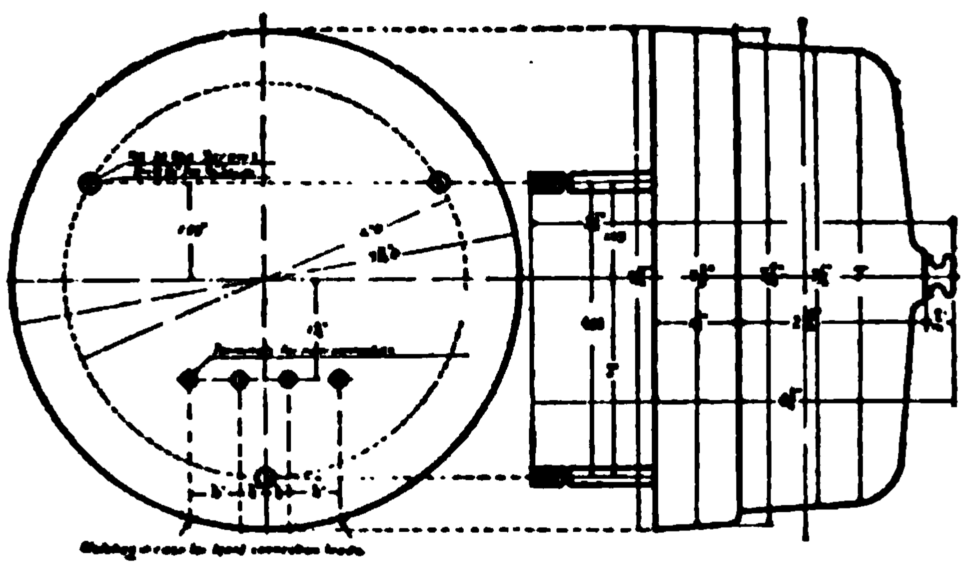


FIG. 710.—Dimensions of Type SC Printometer.

increment in the reading of the Printometer, will give the value of the multiplier.

A more accurate check may be made by determining the number of revolutions of the moving element of the watt-hour meter necessary to bring up each number on the lowest cyclometer wheel. This number multiplied by the watt-hour constant of the watt-hour meter and by 1,000, gives the multiplier M.

This device is manufactured by the Chicago Electric Meter Company.

Dimensions of the Type *SC* printometer are given in Fig. 710.

There are two general forms of maximum load indicating devices manufactured by The Chicago Electric Meter Company, for connection to watt-hour meters. They are, first, the Maxicator, which is a combination of maximum load indicating register and watt-hour meter register, which takes the place of the original mechanism on the meter, and second, the Universal Maxometer, which is a maximum load indicating device. electrically connected to any watt-hour meter.

The Maxicator consists of four dials like those of the watt-hour meter for showing the total consumption, and in addition a fifth dial of larger diameter, which is used for indicating directly the maximum demand in kilowatts, during any half-hour interval. The time interval of one-half hour is obtained by means of a contact-making motor, mounted without the meter and connected to the Maxicator proper by two wires passing through the watt-hour meter case. This device consists of a single-phase, self-starting, induction motor, which operates a contact mechanism through a train of reduction gearing. This contact energizes the solenoid contained within the Maxicator, which performs the operation of resetting (Fig. 711).

FIG. 711.—Contact-Making Motor of Maxicator.

Fig. 712 shows a front view of one particular type of Maxicator. The four dials and dial hands, *A*, are those giving the register reading and are like the dials and dial hands of the ordinary watt-hour meter register. The fifth dial hand, *B*, is the maximum load indicator, recording on the larger external scale, *C*. As shown in Fig. 713, this dial hand is not connected directly in the train of gears, but is merely held in place on the scale, *C*, by means of a leaf spring, *D*. A driving dog, *K*, when engaged with the first dial hand will revolve the large dial hand at a rate directly proportional to the consumption of energy passing through the watt-hour meter as though it were a part of the recording train. Such driving will be continued until the end of the half-hour interval when the solenoid will be energized by means of a contact-making motor, and the core, *A*, will be instantly moved upward to its seated position. This action will move upward a rack mounted upon a spindle, and connected to the

screw, *B*, Fig. 713, revolving the pinion and ratchet, *D*, backward to a definite zero position. The driving dog, *K*, being directly connected to this ratchet, is also revolved back to zero position, thus opening the mechanical connection between the dial train and the dial hand, *B*. The dog, *K*, will again be revolved by the watt-hour meter, which, through the gear mechanism, will revolve the dial hand, *B*. There will, however, be no driving upon the friction dial hand, *B*, unless the consumption of energy for this interval is greater than that of the preceding. If it is greater, the dial hand is picked up and carried to some advanced position. If the consumption is less, however, the driving dog, *K*, will not reach the dial hand, *B*, before the end of the interval

FIG. 712.—Front View of Maxicator. FIG. 713.—Rear View of Maxicator.

and will, therefore, be returned to the zero position without increasing the indication of the Maxicator. It will, therefore, be seen that the friction dial hand, *B*, will indicate the maximum consumption obtained during any half-hour interval. The Maxicator, by means of a falling weight escapement, entirely relieves the watt-hour meter of the work of driving the recording mechanism. The core, *A*, Fig. 713, of the solenoid, acting through a rack and pinion when falling, has sufficient power to drive the friction of the gearing and friction dial hand, and therefore the tendency of the dog, *K*, is to rotate in a forward direction at a high speed, which would, if unrestrained, drive the watt-hour meter moving element. The worm and worm wheel of the recording mechanism act as an escapement on this falling weight, since it is impossible to drive the worm of the watt-hour meter through the worm wheel. It may, therefore, be seen that the speed of the falling weight will be dependent upon the speed of the watt-hour meter moving element. By this form of construc

tion practically all friction is removed from the watt-hour mechanism actual test showing that many types of meters will operate one per cent faster with the Maxicator in place than with no watt-hour meter register installed.

The Maxicator is manufactured in three distinct types, known as Type *G*, for General Electric watt-hour meters, Type *W*, for Westinghouse watt-hour meters, and Type *F*, for Fort Wayne watt-hour meters. The mechanisms of these various forms are exactly similar, the only difference being found in the shape of the dial face mounting plates, in order to conform to the requirements of the various types of meters. The three types of Maxicators are designed especially for five ampere, 220 volt, single and polyphase, watt-hour meters.

For larger capacities, potential and current transformers may be used or larger watt-hour meters with a register constant applied to the register reading. The Maxicator may be used upon continuous current watt-hour meters, by employing a suitable register constant.

Since the Maxicator is a device which virtually replaces the register of the watt-hour meter upon which it is used, the only calibration required is that of the watt-hour meter itself, with the Maxicator installed This calibration may be performed by any of the approved methods given in Chapters VII, VIII and XVI.

The Universal Maxometer is mounted entirely without the watt-hour meter to which it is connected, and consists simply of a maximum load indicating dial hand, electrically interlocked with the register of the watt-hour meter. The electrical connection is obtained through the use of the contact-making commutator, mounted upon one of the spindles of the dial train, which closes the circuit of the solenoid and operates the ratchet and pawl mechanism within the Maxometer. Mounted in the same case is either a single-phase, self-starting, induction motor, a continuous current motor, or an electrically wound clock, which operates the resetting mechanism through a train of reduction gearing.

The dial is calibrated to read the maximum load in kilowatts, either with, or without, a register constant, depending upon the capacity of the watt-hour meter.

A cyclometer mechanism exactly like that used in the Printometer is employed, in this device, for driving forward the indicating dial hand. A contact-making commutator mounted upon one of the spindles of the watt-hour meter dial train operates a coil contained within the Maxometer. The core of this solenoid, through a ratchet and pawl mechanism revolves the driving dog, step by step. This engages with a second dog. mounted upon a spindle of the friction dial hand, and advances it at the same rate. As the driving dial hand revolves, a helical spring mounted

upon this shaft is slowly wound up. In alternating current installations a single-phase, self-starting, induction motor, and in continuous current installations, a continuous current motor, or an electrically wound clock, lifts through the reduction gearing, a weight which at the end of a half-hour interval falls and releases the mechanism, holding the driving dog in place against the tension of its set-back spring. The dog is then revolved at a high velocity to zero, and at the end of its stroke, a pin, by striking against the lever of the release mechanism, re-engages the train, thus allowing it to travel forward as before. The friction dial hand, however, is not in any way affected by the set-back. It will, therefore, be seen that the friction dial hand at the end of a week or month will indicate the maximum position reached by the driving dial hand. This will, of course, be the maximum demand, or load.

An approximate calibration of the Universal Maxometer may be obtained by operating the watt-hour meter at full load for a length of time, such as a half hour, with the Maxometer electrically interlocked with the watt-hour meter register. The number of kilowatt-hours, which have passed through the watt-hour meter during the interval, divided by the reading of the Maxometer dial should give the multiplier, *M*, which is marked on the dial face. The multiplier may be accurately checked by determining the number of units of consumption as recorded on the dial for one revolution on the contact-making commutator.

Graphic recording instruments are obtainable in many varieties and makes and give an accurate record of all the variations in the load measured, but, as a rule, are so expensive either in first cost or operation as not to be suitable for general use on consumers' premises. For special and station purposes their use cannot be too highly recommended.

For these purposes they may be used to advantage in connection with watt-hour meters, the former making a continuous graphic record of the instantaneous values in kilowatts or other desired units of the electrical power used, at any time, and the latter recording the total number of kilowatt-hours of electrical energy during a given period.

From the curve drawn by the graphic recording instrument, the value of instantaneous peaks; the time of occurrence of peaks or other characteristic loads; the average value of the load and the amount of fluctuation in the load can be read off or calculated. This allows the application of different rates for different load characteristics and different times of day.

As the "load wave" is really what is indicated by this type of meter, it gives a definite basis for rates to consumers whose demands for electric power during different hours of the day can thus be determined.

Graphic recording meter records are invaluable as an aid to scientific management in central stations and industrial plants of all kinds. Their value is realized by skillful managers and their use is being extended to new fields. Central stations use the records to determine a fair basis for charges according to maximum demand and hours of service, and to reduce operating expenses by arranging a proper schedule for the operation of machinery and attendance of operators according to the regular demands. Large manufacturing plants use them to determine and analyze the power requirements and operating cost of motor-driven machinery. Large printing plants and newspapers find them of advantage in obtaining automatically a continuous record of the speed and output of

Fig. 714.—Bristol Planimeter for Integrating Graphic Recording Instrument Charts.

their presses. Many factories, textile mills, and machine shops are using them to analyze the cost, both in power and in time, of their various operations, with a view to eliminating time lost and excess power used

The advantages of using graphic recording meters lies in the fact that they record electrical measurements automatically and with reference to time. If indicating meters are used for the same purposes, numberless observations have to be taken and curves plotted, with likelihood of errors, while watt-hour meters, though they record the total energy consumed, do not afford the detailed information relative to time variations of load, that are necessary for an intelligent analysis of costs. If the

clerical work necessary to translate indicating instrument, or watt-hour meter, records into intelligible and useful form is considered, it will be probably found that a graphic recording meter that gives accurate records automatically in the form required, involves less total expense.

The curve drawn, having ordinates proportional to the kilowatts used during every instant and a base line proportional to time, can be integrated with a planimeter to compute kilowatt-hours, but for this purpose the maximum load indicators recording in kilowatt-hours for a given period, as described in previous paragraphs, are preferable (Fig. 714).

Fig. 715.—Westinghouse Graphic Recording Instrument

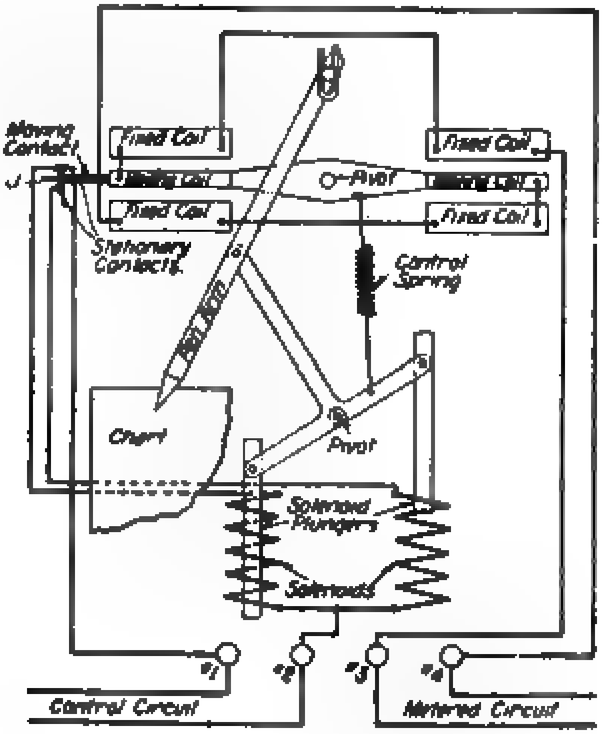


Fig. 716.—Internal Connections of Westinghouse Graphic Recording Instrument.

A few types of graphic recording instruments are described and illustrated below:

The **Westinghouse graphic recording instruments** (Figs. 715 and 716) operate on the relay principle, the meter element actuating only contacts and not moving the pen directly. In turn, these contacts energize a pair of solenoids arranged to move the pen. The solenoids are wound for operation from either alternating or continuous current circuits, as desired.

The meter elements of alternating current and continuous current watt meters are similar to Westinghouse precision meters, i.e. they are of th

Kelvin balance type. They are independent of variations in frequency, external fields, temperature, power factor or wave form. Continuous-current ammeters are of the permanent magnet type with moving coils, and operate from shunts.

The power required for the meter elements is not greater than that for the Westinghouse indicating meters.

The control circuit for operating the solenoids is generally 110 volts continuous current, the allowable temporary variation of voltage being 25 per cent above or below normal. Where such a circuit is not available other solenoids, suitably wound, may be provided. When the only continuous current supply available is an exciter circuit controlled by an alternating current automatic voltage regulator, alternating current control meters should be used.

The record is made by a pen which is moved in a straight horizontal line across the paper, the motion being at right angles to the motion of the paper, thus giving a scale having rectangular co-ordinates.

The pen is of self-feeding design and has a reservoir containing a one month's supply of ink. It operates on the capillary principle and the feed is uniform at all temperatures. The marking point is a hard iridium alloy tube.

The motion of the pen and consequently the sensitiveness of the meter may be regulated. Thus the record may be made either to show every slight variation in the circuit or to slur over these irregularities and form a more even line. The pen can be made to travel full scale in any time from 1 to 30 seconds (Fig. 717).

The paper for these meters is supplied in a long roll so that continuous records may be kept for any desired period. The width is approximately six and three-quarter inches, five and one-quarter inches of which is utilized for the record. Standard rolls are of sufficient length for two months' service when run at a speed of two inches per hour. The standard paper speeds may be 2, 4 or 8 inches per hour. Each meter has a paper collecting roll that will take up about two weeks' length of record without necessity of removing same.

The clock, which turns the paper rolls, is of the electric self-winding type, power for winding being taken from the control circuit at the end of each two-inch period.

A synchronizing attachment for connection to a general contact-making master clock operated by a Western Union time service wire, can be furnished. This device consists of an electromagnet, energized once per hour, which corrects for any variations in the running of the clock. Thus, any number of meters in the same station, or system, may be kept synchronized. This synchronizing device cannot be furnished in the

United States unless arrangements are made for time service with the Western Union Telegraph Company.

The ink furnished with these meters is furnished in concentrated form to be added to distilled water, making a writing fluid containing a minimum of solid matter. The ordinary commercial writing inks are not recommended, as they cause the pen points to clog. A green ink has been found to be the most satisfactory as to legibility and pen action.

All meters are designed for switchboard mounting only, and are en-

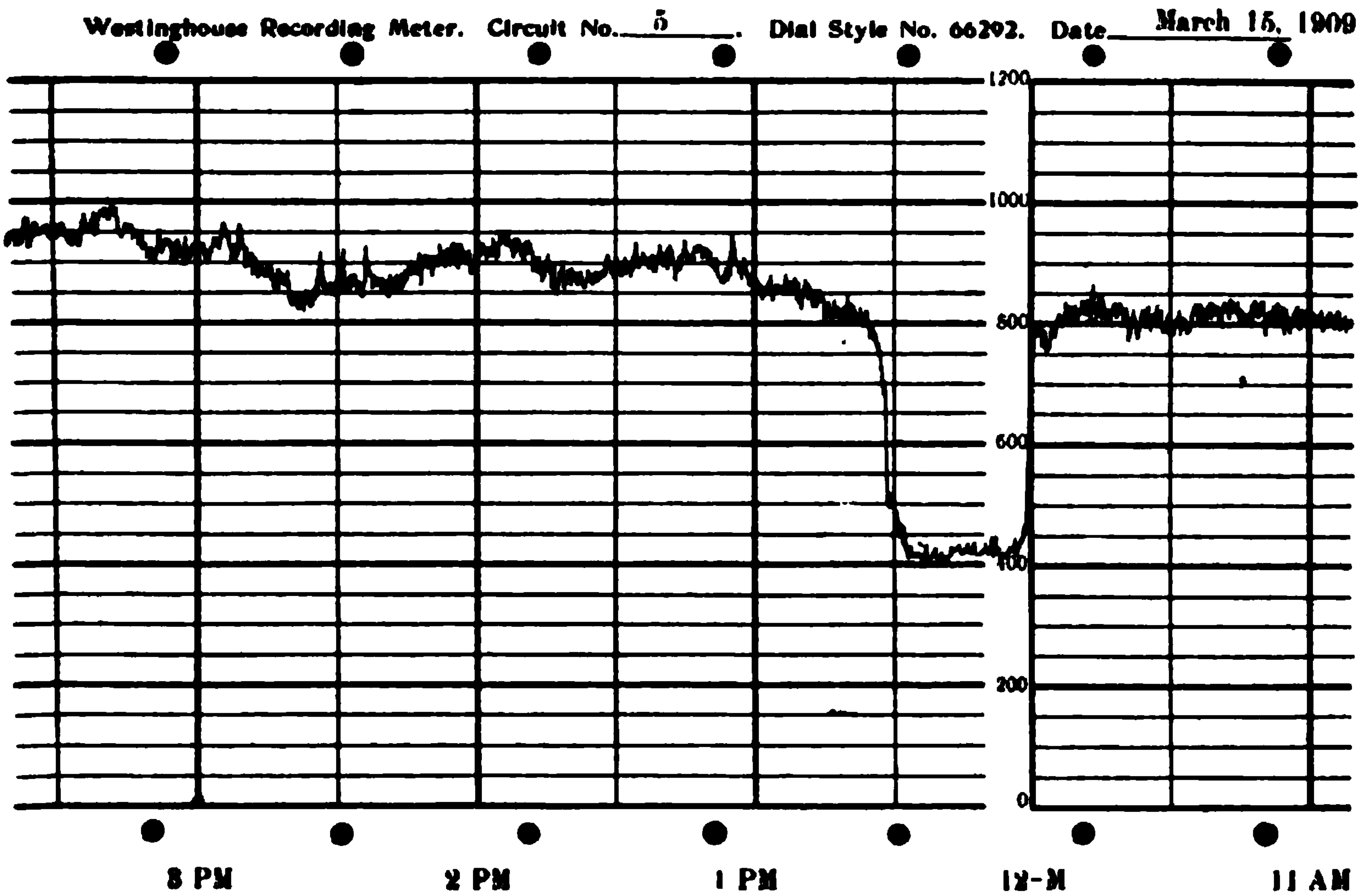


FIG. 717.—Westinghouse Graphic Recording Instrument Chart Showing Fluctuations in Load.

closed in glass cases with removable hinged glass front, giving access to the interior.

The **General Electric Company's graphic recording instruments** for alternating current (Figs. 718 and 719) are constructed on the direct-reading dynamometer principle. Single-phase wattmeters have one fixed and one movable set of measuring coils; polyphase wattmeters have two sets of fixed coils and two sets of movable coils, the latter rigidly attached to a common shaft. The ammeters are constructed on the magnetic vane principle.

The movable element of these instruments is suspended entirely from the top by means of a steel piano wire. The lower end is centered by a small steel pivot passing through a ringstone sapphire jewel

The pen depends for its acti
tion. The point consists of an
bulb at the extremity of this gl.
pen one week without refilling.
made of seamless aluminum tul
in sapphire jewels.

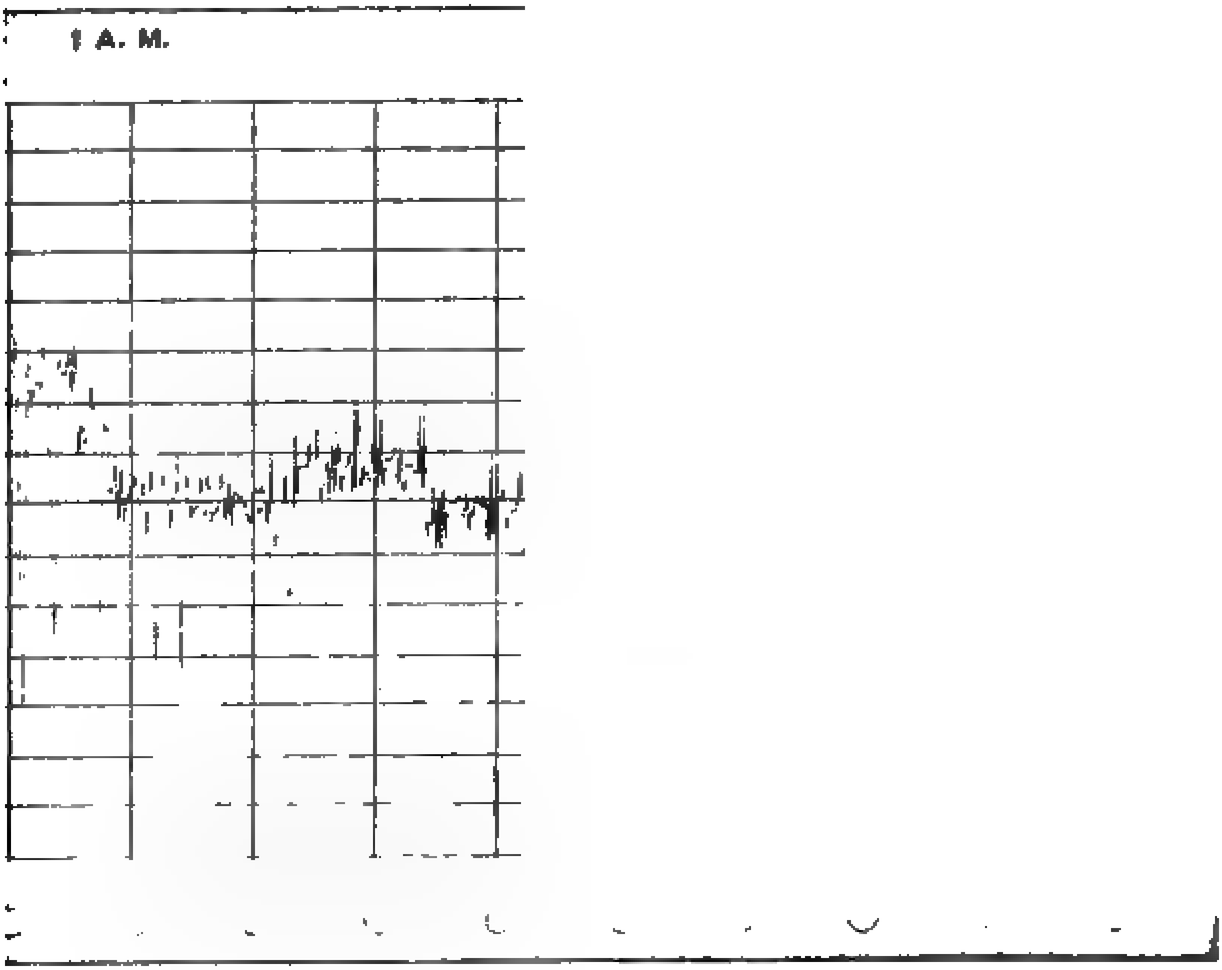


FIG. 718 —General Electric Recording Instrument Chart Showing Fluctuations in Load

These jewels are carried at the ends of arms attached to the shaft which carries the movable element.

The clock has an eight-day movement and must be wound at least once a week, but since the torque is maintained at a more uniform value if the spring is not allowed to become completely unwound, it is recommended the clocks be wound twice a week. At the right of the clock projects a metallic finger by means of which the mechanism may be started or stopped at will. Means are also provided for regulation.

The record is made on a band of paper four inches wide and sixty

feet in length. On this paper are ruled lines corresponding to the time and instrument calibration. The lines ruled across the paper represent time, those ruled lengthwise represent amperes or watts, depending upon the instrument construction.

FIG. 719.—General Electric Graphic Recording Instrument, Switchboard Type

FIG. 720.—General Electric Graphic Recording Instrument, Type CR, Portable

FIG. 721.—Internal View of General Electric Graphic Recording Instrument, Type CR

The recording pen is attached to the movable element in such a manner that its motion is transmitted in a straight line parallel to the time division on the chart.

The standard rate of chart feed is three inches per hour, although feed of one inch or six inches per hour will be supplied if desired.

The scales of all these instruments are three and one-eighth inches in length.

The instrument indications are rendered dead-beat by means of a damping disk of aluminum passing between the poles and across the fields of permanent magnets.

The instruments are shielded from the influence of external magnetic fields. They are free from heating errors and may be used on circuits of any wave form or power factor.

The standard finish is dull black. Instruments are enclosed in a glass case and are rendered dust-proof by means of felt guards or cushions.

The continuous current graphic recording wattmeters, with the exception that they are calibrated on continuous current, are the same as the alternating current instruments.

The continuous current graphic recording ammeters are constructed on the astatic principle, and are of the electromagnet type. The moving element consists of two rectangular shaped coils connected together with two soft, sheet steel, astatic control pieces. The current to be measured or a shunted portion of it, is passed through these coils which are free to move in the fields set up by two astatically arranged electromagnets. The movement of these coils is opposed by the counter torque of the astatic control pieces and also by two control springs.

The standard electromagnets are wound for 125,250 and 550 volts. The instruments have been so designed that a 25 per cent variation above or below normal will cause no appreciable error.

Owing to the astatic arrangement of the magnets and control pieces, the instruments are practically free from errors due to stray fields, and are free from errors due to hysteresis and change of temperature.

Type *CR* graphic recording instruments, Fig. 720, are of the round pattern type, having circular charts eight inches in diameter.

The internal parts of these graphic recording instruments consist of the clock mechanism and the measuring element. The spindle carrying the pen arm has cylindrical pivots and runs in ringstone, end-stone jewels.

The electrical circuit is of the solenoid type with gravity control. They can be operated on either alternating or continuous current. To render the needle dead-beat, an aluminum damping disk is operated from the armature shaft through gearing so that a large movement of the disk is obtained with a small movement of the pen.

The pen consists of a V-shaped metal punching with a sharp point. Under ordinary conditions, it will hold sufficient ink for several charts.

The clock, with ordinary chart speeds, will run two days with one winding.

The driving arbor to which the charts are attached projects through the inner case, and the chart is clamped in place by a knurled nut. The chart is supported by a stationary metal dial, and, to keep it flat, the edge runs under six clips on the periphery of this dial.

The standard clock speed is arranged to drive the chart through one revolution in either 12 or 24 hours. Speeds of one and six hours can, however, be furnished on request.

The standard finish is dull black. All instruments have a circular glass window in the cover, which renders the entire record visible at all times.

The principle upon which the **Sangamo graphic recording instruments** operate depends upon the fundamental law that current passed at right angles through a magnetic field is urged at right angles both to the current flow and the field.

The measuring elements comprise a mercury floated metallic disk, or sector, moving element and a stationary element consisting of electromagnets in the alternating current ammeters, alternating current wattmeters and continuous current wattmeters. The continuous current ammeter employs permanent magnets.

The instruments are of the direct deflection type, without the use of relays, or control magnets.

In addition to the recording feature each meter is provided with an indicating scale, which answers the purpose of indicating ammeters or wattmeters.

The recording pen is so formed as to provide an ink reservoir of sufficient capacity for several days' use. The pen point is composed of a metal alloy.

The clock is of the eight-day, enclosed type, the function of which is to drive a record paper under the recording pen at a uniform predetermined rate, synchronous with the time markings on the record chart.

The record paper, 248 feet in length and six inches wide, is graduated longitudinally in a set of parallel lines representing the meter calibration, the spacing being uniform with the various capacities, but of different values. At right angles to the calibration lines are parallel lines representing hours, varying in distance from each other with the particular rate of speed for which the record paper is marked.

Speeds of two inches, four inches and eight inches per hour may be obtained by substituting gears and pinions having different ratios of teeth. Any desired speeds up to sixty inches per minute can be furnished.

The meters are free from the disturbing influences of external magnetic

fields generated by heavy curents, or
the meters.

The movable element of the meas
dered aperiodic, by the dash-pot act
through the mercury chamber.

The **Bristol graphic recording inst**
are of the round dial pattern, with eigl

FIG. 722.—Bristol Graphic Recording Instruments, Switchboard Type.

and 726). They can be used on both alternating current and continuous current circuits and are of the solenoid type.

Fig. 722 shows the interior construction and manner of operation. In a wattmeter a coil wound with fine wire is mounted on spring knife-edge supports and is free to move toward a stationary coil, which is wound with a heavy conductor capable of carrying the entire current to be measured. The terminals of the movable coil are connected to the positive and negative conductors, and the magnetic effect of the current through this coil of high resistance will be dependent upon the voltage, while the magnetic effect of the main current through the sta-

Fig. 723.—Bristol Graphic Recording Instrument, Portable Type.

tionary coil of low resistance will depend upon the number of amperes passing. The mutual attraction of the coils will be the product of these magnetic forces and proportional to the number of watts. A marking arm is attached directly to one of the knife-edge spring supports of the

Fig. 724.—Bristol Graphic Recording Instrument, Weatherproof Type.

movable coil and partakes of its motion, recording the variations of electrical energy on a uniformly revolving chart.

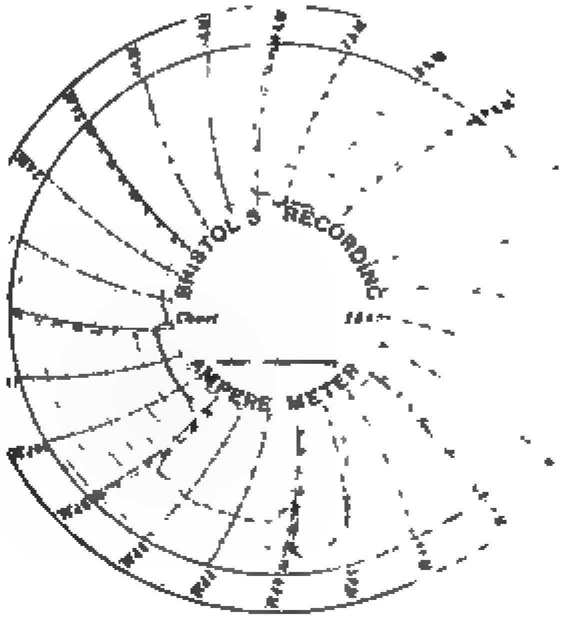


FIG. 725.—Smoked Chart from Bristol Graphic Recording Instrument.

FIG. 726.—Ink Chart from Bristol Graphic Recording Instrument.

The magnetic balance principle is involved in the construction and there are no permanent magnets.

FIG. 727.—Esterline Graphic Recording Instrument, Switchboard Type.

The Esterline graphic recording instrument (Fig. 727) is an instrument which makes a continuous record on a paper chart automatically fed at a uniform rate by the mechanism of the instrument.

The instruments are made in four types, viz., switchboard, wall, desk and portable types. The portable type is mounted in an aluminum case, fitted with carrying handle, eccentric lock and rubber feet. A plate glass window is provided, making the record visible The front opens downward, and by pushing to right when open, it can readily be removed (Fig 728).

The clocks used in all Esterline graphic recording instruments are a jewel balanced, eight-day movement, mounted in a dust-proof metal case. A small plate glass window is provided to give access for adjustment, and to enable the operator to see that the clock is running.

The chart feeding mechanism is also contained in the clock case.

FIG 728.—Esterline Graphic Recording Instrument, Portable Type.

The paper is drawn through the instrument by the feeding mechanism, the clock regulating the rate of chart feed.

The feeding mechanism also constitutes the re-roll, which rolls the record up as it is printed.

The ink well is stationary, and the ink is siphoned from the ink well through the indicator of the instrument, at the end of which is an inking pen.

An indicating scale is mounted just above the pen tube, so that the instrument constitutes a combined edgewise indicating and graphic recording instrument.

A partition divides the interior of the instrument case into two compartments; the clock and chart controlling mechanism are placed in the front part of the case. The meter element and other parts are placed back of the partition. The partition is hinged, so that the

clock and record roll can be swung out of the way, exposing the meter element and instrument wiring to view.

The chart feeds which can be furnished in a single instrument are

$\frac{3}{4}$ in., $1\frac{1}{2}$ in., 3 in., 6 in., and 12 in. per hour
$\frac{3}{4}$ in., $1\frac{1}{2}$ in., 3 in., and 6 in. per minute.

The standard chart feed is three inches per hour. The change from one to another rate of feed per hour, or from one to another rate of feed per minute, is made by changing gears on studs on the outside of the clock case. Instruments are not provided with "minute" feeds unless so ordered, and these feeds cannot be supplied after an instrument has been shipped, since this requires additional gears inside the clock case. Gears for outside of clock case can be furnished at any time.

Record charts are in rolls 90 feet in length, and will last 30 days continuous operation at $1\frac{1}{2}$ inches per hour.

Change of chart feed from inches per hour to inches per minute, or vice versa, in instruments provided for "minute" feeds, is made by a small lever projecting from the front of the clock case.

Record charts are 6 inches wide, with a scale $4\frac{1}{2}$ inches in width.

The meter elements used in each type of instrument are adapted to the requirements of each case.

Continuous current graphic recording ammeters and voltmeters have meter elements of the D'Arsonval type.

Alternating current graphic recording instruments, and continuous current wattmeters, have meter elements of the dynamometer, moving coil type.

All meter elements are designed so as to operate with standard shunts and voltage and current transformers.

These instruments are manufactured by the Esterline Company, La Fayette, Ind.

The Brown Electric Recorder (Figs. 729 and 730), or graphic recording instrument, has been designed with the d'Arsonval type of meter element for continuous current, and for alternating current, the electromagnetic, or soft iron type. The friction between the recording pen and the chart is removed by the recording pen being brought into contact only momentarily every half or quarter minute with the chart.

The whole electrical system is mounted on the door, so that when the door is swung open the pen arm is moved aside and the record chart can be changed without interference with the recording pen arm.

A bracket is carried beside the pen point, and this bracket is normally pushed away from the pen by clock mechanism and lever shown at the left of the photograph. Every quarter or half minute

FIG. 729.—External View of Brown Electric Graphic Recorder

it is allowed to fall, pressing the pen against the paper and leaving a dot of ink.

The chart is printed on ordinary white paper which does not require coating or treating of any kind, and the record can be filed, if desired, as soon as removed from the instrument.

In The Brown Portable Electric Recorder, the instrument is used horizontally, the recorder being placed on a bench or table.

The clock mechanism is carried on a drawer with guides upon which it slides as the drawer is drawn out, the chart drops away from the recording pen and prevents marking of the chart. On account of this construction the chart can be changed with the drawer removed from the instrument, the pen arm being out of the way entirely

FIG. 730.—Internal View of Brown Electric Graphic Recorder.

In many instances it is preferable to use a graphic recording instrument which will keep a continuous record for a week or month, for which a circular record chart is not so desirable. With this in view a type was designed, carrying a two months' roll of record paper and requiring winding once a week The electrical features of design are similar to those of the circular chart instrument

This instrument is manufactured by the Keystone Electrical Instrument Company, Philadelphia, Pa.

All of the above graphic recording types of instruments record only antaneous values and must be integrated by some means, in order tain average demands over any given interval of time

CHAPTER XVIII

SPECIFICATIONS FOR ACCEPTANCE OF WATT-HOUR METER TYPES

CHAPTER XVIII

Specifications for Acceptance of Watt-hour Meter Types

During the last decade manufacturers have exerted their utmost energies toward improving the electricity meter, with the result that very marked advances have been made. Many of the meters produced ten years ago are no longer being manufactured and have been superseded through improvements in design. New types have taken their places, and to-day exceedingly accurate electricity meters can be secured for every class of service.

Great care should, however, be exercised in **deciding on the particular type and make of electricity meter** to purchase. A laboratory test is advisable (see Chapters V and VII), as indicating the performance of the meter under ideal conditions. In the laboratory a minute examination can be made of the quality of the workmanship, the excellence of the design, the range of adjustment of the different parts and the accuracy of the meter under prescribed conditions. Too much stress, however, should not be laid upon the results of the laboratory test. Almost any meter can be adjusted in the laboratory to show a satisfactory test, but such a test is no indication of the ability of the meter to maintain its accuracy under the vicissitudes of actual service.

In addition to the laboratory test, it is necessary to conduct a series of **tests on** a number of **meters in actual service** and in different localities, in order that the meters may be subjected to the varying local conditions; such as vibration, dust and moisture, extremes of temperature, short circuits, et cetera. (See Chapters VII and VIII.) During the period covered by the service tests, it is necessary to test the meters repeatedly for accuracy, and it is usually undesirable to calibrate the meter at such times, as the object to be attained is the determination of the period during which the meter will operate within the limits of commercial accuracy.

Some companies are still using the **commutator type of watt-hour meter,** also the old induction type of ampere-hour meter, on alternating current circuits. Formerly it was considered that the commutator type of watt-hour meter was equally desirable for both continuous and alternating current circuits, and when the meter was

properly compensated it registered with equal accuracy in the majority of cases on both classes of current. To-day, the commutator type of watt-hour meter is generally considered as a continuous current meter, and the **induction watt-hour meter** is considered preferable for alternating current circuits for various reasons, among which may be mentioned:

The induction watt-hour meter will generally maintain its accuracy for longer periods.

Brush and commutator troubles are eliminated.

Lighter moving element, resulting in a longer life of the jewel and pivot.

Generally occupies less space.

Shunt losses are less.

First cost generally less.

Maintenance cost is generally less.

More accurate on inductive loads, as the ordinary commutator meter is not compensated for these loads.

Ampere-hour meters of the old induction type are no longer being manufactured. These meters are very inaccurate, especially on inductive loads, and they should be discarded and be replaced by the induction type of watt-hour meters, which are accurately compensated for inductive loads. There is recently, however, a well-defined increasing tendency to revert to the use of a modern well-designed, inexpensive type of ampere-hour meter, in low capacities, on the services of small consumers, where the revenue derived does not now justify the investment for a watt-hour meter and where the energy recorded does not involve such delicate limitations as are procurable in watt-hour meters.

The various meter manufacturers have been requested jointly by the National Electric Light Association's Committee on Meters, and the Association of Edison Illuminating Companies' Committee on Meters to **standardize**, so far as possible, **many features in watt-hour meters** that are of special interest to central station companies. The following features have been recommended:

(1) Wires to enter watt-hour meters at the bottom, the feed, or service, wires being on the left.

(2) The rotating elements of all watt-hour meters to revolve in the same direction, from left to right, facing the front of the disk.

(3) Uniform range of watt-hour meter capacities to be generally adopted.

(4) A four dial register to be standardized and all markings eliminated from the dial face, other than the numbering of the dial divisions

and the value of the unit of registration, or, when necessary, the constant to be used to convert the reading into that value, which should be placed below the arrangement of dials.

(5) Definite names to be adopted for the various watt-hour meter constants, and the values assigned to each to be in terms of the same units; as watt-hours or watt-seconds, and so on. (See Chapter XV.)

The following is a brief **summary** of the principal **specifications** covering an acceptable type of meter as laid down in the Code for Electricity Meters.

1. Initial Accuracy of Registration: Continuous current meters shall run continuously at 2 per cent rated current and shall record

within ±7.5 per cent at 5 per cent rated current
within ±3 per cent at 10 per cent rated current
within ±2 per cent at 100 per cent rated current

Alternating current meters shall register

within ±3 per cent at 5 per cent rated current
within ±1.5 per cent at 100 per cent rated current

2. Effect of Variation in Power Factor: A power factor of 75 per cent shall not cause more than ± 2 per cent, and a power factor of 50 per cent shall not cause more than ±4 per cent variation in the registration of the meter at either light or full load.

3. Effect of Variation in Voltage: In continuous current meters a variation of ± 10 per cent voltage shall not cause an error of more than ±5 per cent at light load, or ±3 per cent at full load. In alternating current meters the corresponding figures are ±2 per cent and ± 1.5 per cent.

4. Effect of Variation in Frequency: The effect of ± 10 per cent variation in frequency at full load shall not be more than ± 1.5 per cent.

5. Equality of Elements at Three-Wire Meters: The elements may not differ by more than ± 2 per cent.

6. Effect of External Magnetic Field: On continuous current meters a uniform field of 0.1 C.G.S. line per square centimeter applied in the direction to have a maximum effect shall not change the rate of the meter by more than 2.5 per cent. For alternating current meters, an arbitrary test is prescribed.

7. Effect of Variation in Temperature: The average temperature coefficient shall not exceed 0.2 per cent per degree between 20° and 40° C.

8. Effect of Temporary Overloads and Short Circuits: For meters less than 600 amperes, 400 per cent overload applied three times, two seconds each time, shall not change the registration by more than ± 5 per cent at light load, or ± 3 per cent at full load. The corresponding values for alternating current meters are ± 1 per cent on both light and full loads.

9. Potential Drop in the Field Coils: This shall not exceed 1.5 per cent of the rated voltage of the meter in meters of less than 10 amperes capacity, or 0.75 per cent in meters of 10 amperes capacity and larger.

For polyphase meters, in addition to the test for independence of elements which has been referred to above, tests are made for the initial accuracy of registration, the limits being as in the case of single-phase meters; for the accuracy of individual elements ± 2 per cent; for the effect of variation in power factor, the limits being the same as for single-phase meters; the effect of variation in power factor of the individual elements, the limits being in this case widened to ± 3 per cent under conditions unfavorable to the accuracy of the meter; also for the other metering features the same as in single-phase meters.

Similarly, current transformers must conform to the following conditions as to variation of ratio from its nominal value and as to phase angle at light load and at full load.

Per Cent of Rated Current	Light Load		Full Load	
	Ratio	Phase Angle	Ratio	Phase Angle
10	± 2%	2° 30′	± 3%	4° 30′
25	± 2%	1° 30′	± 2%	3°
50	± 2%	1°	± 2%	1° 30′
100	± 2%	1°	± 2%	1°
150	± 2%	1°	± 2%	1°

In voltage transformers the ratio may not deviate by more than 2 per cent of its nominal value and the phase angle shall not exceed one degree with either light or full load. Ten per cent variation in the voltage of a voltage transformer shall not cause a change of more than 0.5 per cent in the ratio of transformation, nor more than 30 minutes in the phase angle.

It may be stated that the above specifications are not intended to cover simply the very best of modern apparatus, nor do they represent the highest results obtainable by the very best types of meters under laboratory conditions, but they are intended to cover such apparatus as should be considered commercially satisfactory and proper apparatus to use at

the present time; that is, the apparatus which was the best of its kind a few years ago would in most cases still be acceptable under the specifications as drawn.

A suggestive list of requirements which constitute a commercially satisfactory service watt-hour meter, and which were compiled by the National Electric Light Association Committee on Meters for 1909, is as follows:

1. Normal curve on non-inductive loads should be practically straight from 5 per cent to 100 per cent load.
2. The meter should register accurately to 50 per cent overload.
3. Errors for a 10 per cent change in voltage above or below the rated voltage of the meter should be small.
4. Errors for a 5 per cent change in frequency above or below the normal should be small.
5. Ordinary wave forms should not cause appreciable errors.
6. Variations in temperature liable to be incurred should not cause excessive errors.
7. The effect of the earth's fields and stray fields on the accuracy should not cause excessive errors.
8. Temporary overloads and short circuits should not cause the moving element to pound, or have any damaging effect on the meter.
9. Should be accurate when operating on circuits having a reasonably low power factor.
10. Should not creep under conditions of vibration or when the voltage is increased, or decreased, 10 per cent from the normal rated capacity.
11. Should not hum, rattle, or otherwise be noisy.
12. Should start to register on a very small percentage of its rated capacity.
13. Friction should be small and should not be variable.
14. Accuracy with the cover on and off should be the same.
15. Accuracy should not be seriously affected, or life of the parts seriously affected, by ordinary vibration.
16. Should be accurate on rapidly fluctuating loads.
17. The meter should have means for readily varying the calibration at full load and light load, and, if it is used on alternating current circuits, of readily adjusting the accuracy on inductive loads; with these adjustments it should be possible to calibrate the meter so as to be absolutely correct.
18. At full load, adjustment should be capable of varying the accuracy by at least 10 per cent above, or below, the correct calibration.
19. The light load adjusting device should have sufficient range to

increase the meter accuracy 10 per cent at one-twentieth load. It is undesirable to have a stronger light load adjustment, as in the latter case a tester is liable to use it to cover up some friction which should be located and eliminated.

20. The adjustment for lagging should have sufficient range to make the meter correct for any ordinary combination of frequency and wave form.

21. All adjustments should be as nearly independent of each other as possible. For example, the changing of the light load adjustment should not produce errors on inductive loads; the lagging adjustment should not produce errors on light load, and so on.

22. Torque should be high.

23. The weight of the moving parts should be low.

24. The combination of 22 and 23 will naturally give a good ratio of torque to weight. It should not be assumed, however, that two meters having the same ratio of torque to weight are equally good. For example, a meter with a torque of 30 and a weight of moving element of 30, which has a ratio of 1, is much better than a meter having a torque of 200 and a weight of moving element of 200, notwithstanding the fact that its ratio is also 1.

25. The initial and subsequent friction should be low. Meters should be so designed that the increase in friction is at a very slow rate.

26. The ratio of torque to friction should be high.

27. The counter-torque produced by the magnets should be very high as compared to the counter-torque produced by friction.

28. All magnets used should be practically permanent and unaffected by vibration, temperature, short circuit, and so on.

29. The magnet, or magnets, should be so placed and so designed that the fields of the current coils have no effect on them.

30. Jewels, pivots and similar bearings should be of the best quality and should be easily removable for inspecting. Meters should be so designed that the jewel can be removed for inspection without altering the relative position of the moving element with respect to the stationary parts.

31. Life of jewels should be long.

32. Energy lost in shunt coils, field coils and other parts should be small.

33. There should be no aging of the iron of the magnetic circuit in induction meters.

34. Meter should not be affected unduly by lightning discharges or surges on the line.

35. All operating parts should be so designed that little trouble or

error is caused through short circuits, open circuit, shifting of parts, and so forth.

36. The springs supporting the jewels in the jewel screws should be of the proper strength and should remain permanent.

37. The accuracy of three-wire meters should be the same whether the load is on either, or both sides, of the three-wire circuit.

38. Polyphase meters should be accurate when the load on the different phases is balanced or unbalanced, and meter element should not affect the accuracy of the other meter element.

39. Meters should be dust, insect and moisture-proof.

40. Weight and size of meters should be as small as possible.

41. All parts should be strong and should stand ordinary handling and transportation without injury.

42. All parts should be readily accessible for testing, inspecting and repairing.

43. The possibility of tampering should be reduced to a minimum.

44. All adjustments should be readily accessible after simply removing the cover.

45. The magnets should have reasonably large air gaps to prevent foreign particles, which may fall on the disk, or adhere to the magnet, from slowing the meter.

46. The insulation between all the parts should be excellent.

47. First cost should be low and maintenance cost low.

48. Parts should be interchangeable and readily replaced to facilitate repairs.

49. The finish of all parts should be such as to prevent deterioration and rusting. The finish of all covers, magnets and like parts should not peel off.

50. The dial face should be large, easily read and have a dull finish so that reflected light will not interfere with the reading.

51. The register should have the meter number and the gear ratio marked on it, but not on the dial face, to prevent error and facilitate checking.

52. The register should be doweled, or otherwise fastened in position in such a manner that it may readily be removed and replaced in exactly the same position.

53. There should be no reading matter on the dial face except the numbering of the dial divisions, and the term "kilowatt-hours," and in addition the words "Multiply by." in case a multiplying register constant is necessary. These should be plainly printed in large letters and figures.

54. Friction due to the register should be small.

55. The register parts should be gold-plated, or otherwise finished so as to prevent rusting or corrosion.

56. The speed of the meter at normal full load should not be high.

57. Means should be provided for protecting the jewel during shipment.

58. Workmanship should be good.

59. Constants for testing purpose should be placed on the meter in plain sight.

60. The sealing of the meter should be easy and effectual.

61. The connections to the service should be simple and easily made.

62. The use of external taps should be avoided as much as possible.

CHAPTER XIX

QUESTIONS FOR METERMEN

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Questions for Metermen

The following is a list of questions which it is necessary for a meterman to be able to answer, in part, or in toto, according to the responsibility of his position and according to the earnestness of his ambition.

It is expected that companies can select from this list such questions as will cover the scope of any examination, or series of examinations, which they may wish to conduct in establishing the standard of efficiency of its metermen.

The answers to the questions may be ascertained by a study of the subject matter in this Handbook.

Questions

1. What is a meterman's relation to the public?
2. What should be the meter tester's attitude toward the consumer?
3. Define the terms:
   (*a*) Volt, ampere, ohm, watt and kilowatt.
   (*b*) Ampere-hour, watt-hour, watt-second, kilowatt-hour.
4. (*a*) State Ohm's law.
   (*b*) If the pressure at the terminals of a certain resistance equal to 19 ohms is 113.5 volts, what will the watts in the circuit be?
   (*c*) If a second resistance of 8 ohms is connected in multiple with the above resistance what will be the resultant current?
   (*d*) If the two resistances are connected in series, what will be the pressure in volts across the terminals of the 8 ohm resistance?
5. What is meant by power-factor, inductance, resistance and impedance?
6. Give example of a non-inductive load; an inductive load.
7. Describe fully, with the aid of diagram of connections the continuous current commutator type watt-hour meter, including
   (*a*) Principle of operation.
   (*b*) Use of commutator.
   (*c*) Angle at which brushes are set with respect to fields.

(*d*) Reason for using silver on commutator and brushes.
(*e*) Object of shunt field coil.
(*f*) Object of magnets.
(*g*) Reason for no iron in the meter.

8. Describe with the aid of a diagram of connections an ordinary induction watt-hour meter, explaining the uses and principle of
   (*a*) Series field, or current coils.
   (*b*) Potential element coils.
   (*c*) The reactance, or lagging coil.
   (*d*) The light load adjustment.
   (*e*) The magnets.
   (*f*) The laminated core.
   (*g*) The disk.
9. How is the rotating field effect produced in a single-phase watt-hour meter?
10. State the advantage of the induction watt-hour meter over the commutator type watt-hour meter for alternating current.
11. What will happen to an induction watt-hour meter if continuous current is connected to it? Why?
12. (*a*) What is meant by "lagging" a meter?
    (*b*) Why is it necessary to lag induction watt-hour meters?
13. (*a*) What is meant by the torque of a watt-hour meter and on what does it depend?
    (*b*) State the "torque" of some type of watt-hour meter with which you are familiar.
    (*c*) Give the advantages and disadvantages of high and low torque and discuss torque-weight ratio.
14. (*a*) What is the approximate watts loss in the potential circuit of a commutator type watt-hour meter?
    (*b*) A modern induction type watt-hour meter?
15. (*a*) What is meant by gear ratio?
    (*b*) Register ratio?
    (*c*) Register constant?
    (*d*) Test constant?
    (*e*) Watt-hour constant?
    (*f*) Watt-second constant?
16. (*a*) How may the gear ratio be determined?
    (*b*) The register ratio?
17. Given a watt-hour meter, how would you proceed to determine the test constant?
18. Write the testing formulas for the various makes of watt-hour meters, using proper symbols for the different quantities.

19. When testing three-wire watt-hour meters with the fields in series, why is one half of the test constant used?

20. (*a*) How is the percentage of accuracy of a watt-hour meter figured from a comparison of the watts indicated and the true watts load, also by a comparison of the time taken for a certain number of revolutions and the correct time?

(*b*) A certain consumer's watt-hour meter tests as follows:

	Rotating Standard		Watt-hour Meter Under Test	
	Test Constant	Revolutions	Test Constant	Revolutions
10% Load......................	0.06	18.21	0.5	2
100% Load......................	0.6	17.62	0.5	20

Calculate the percentage of accuracy of the consumer's watt-hour meter.

21. How are the different types of two-wire and three-wire watt-hour meters connected?

22. How may the registration of a watt-hour meter be affected.

(*a*) If the current coils are connected in the grounded wire of the system?

(*b*) If the current coils of a three-wire meter are connected in opposition?

23. Will a 230 volt, three-phase watt-hour meter measure correctedly a 115 volt lighting load and a 230 volt power load?

24. With a three-wire circuit, if some of the lamps were very dim and others very bright, where would you expect to find the cause?

25. Draw the connections for metering a high potential three-wire, three-phase circuit, with two single-phase watt-hour meters, using current and voltage transformers.

26. Will a 230 volt, three-phase watt-hour meter measure correctly the energy used by a 230 volt single-phase motor, and a 230 volt three-phase motor?

27. Can a 115 volt load be connected to a 230 volt three-phase watt-hour meter so as to register correctly?

28. (*a*) Describe the procedure when testing a commutator type watt-hour meter on the consumer's premises, giving in detail each operation in proper order from the time of arrival until that of leaving.

(*b*) Give the same for a single-phase induction meter.

29. Show by means of diagram how the consumer's load should be shunted, and how standard instruments and artificial loads should be connected for testing different types of watt-hour meters.

30. (*a*) How would you obtain a testing load for a 150 ampere, two-wire, 220 volt watt-hour meter on continuous current?
 (*b*) On alternating current?
 (*c*) What types of load devices are preferable for continuous current and for alternating current watt-hour meters?
31. What is the minimum number of revolutions that should be taken at 10 per cent load and 100 per cent load on a 10 ampere, 110 volt, watt-hour meter, with constant 0.5?
32. Draw a diagram of connections for testing a three-wire watt-hour meter with indicating instruments using an auxiliary load in conjunction with the load on the premises.
33. (*a*) If a commutator type watt-hour meter has been standing disconnected for some time, is it necessary to allow the voltage circuit to warm up before testing the meter? If so, how long and why?
 (*b*) Is it necessary in the case of an induction meter? If so, how long and why?
34. (*a*) Is the accuracy of a commutator type watt-hour meter affected equally on all loads by adjusting the shunt field?
 (*b*) Is the accuracy of a commutator type watt-hour meter affected equally on all loads by adjusting the drag magnets?

NOTE: Explain the action of the shunt field and of the drag magnets in your answer to these questions.

35. (*a*) What is a consequent pole in a permanent magnet?
 (*b*) What is the effect of a brake magnet on the accuracy of a watt-hour meter if it has a consequent pole of considerable magnitude?
36. What causes a commutator type watt-hour meter and an induction watt-hour meter to run:
 (*a*) Slow on both light load and full load?
 (*b*) Fast on both light load and full load?
 (*c*) Slow principally on light load?
 (*d*) Fast principally on light load?
37. What is meant by the following, and why are they necessary:
 (*a*) Light load adjustment?
 (*b*) Full load adjustment?
 (*c*) Inductive load adjustment?
 (*d*) What effect do these loads have on each other?
38. How would a short circuit in the shunt field coil, impedance coil or series field coil affect the full load speed of a watt-hour meter?

39. What are some of the reasons for a watt-hour meter running backward?
    (*a*) Internal causes peculiar to the meter itself.
    (*b*) External to the meter.
40. What is meant by polarity effect on continuous current commutator type watt-hour meters and will it affect the meter accuracy?
41. (*a*) Explain what is meant when a meter is said to be "creeping," and give all possible causes for it.
    (*b*) How would you determine the "creep" on a watt-hour meter and how is this expressed (in what units)?
    (*c*) How would you stop the creep on a continuous current watt-hour meter? On an induction watt-hour meter?
    (*d*) What anti-creeping devices may be used, and how are they applied?
42. Answer the following questions regarding commutator type watt-hour meters:
    (*a*) When do commutators and brushes need cleaning?
    (*b*) What causes sparking at the brushes? Describe remedies.
    (*c*) What methods are used to determine the correct brush tension?
43. (*a*) How would you determine an open circuit in the armature?
    (*b*) A short circuit in the armature?
44. How would the full load speed of a watt-hour meter be affected, if the following trouble existed:
    (*a*) Open, or short, circuited armature?
    (*b*) Open, or short, circuited resistance?
    (*c*) Open, or short, circuited shunt field coil?
45. Why is a Type M Thomson watt-hour meter armature given a quarter turn on the shaft with respect to the segments, and not a Type C Thomson watt-hour meter?
46. (*a*) What types of indicating instruments are suitable for operation on continuous current?
    (*b*) On alternating current?
    (*c*) On both continuous and alternating current?
47. Describe the general characteristics and the principle of operation of each.
48. What are the sources of error resulting from improper use of the following instruments:
    (*a*) Continuous current voltmeters and ammeters?
    (*b*) Electrodynamometer types of voltmeters, ammeters and wattmeters?
    (*c*) Continuous current, rotating standards, and alternating current, rotating standards?

(*d*) Millivoltmeters with shunts?
(*e*) Stop watches?
(*f*) What is the best means of detecting the above errors and eliminating their effect?

49. Describe in detail the best methods of arriving at an average reading of a passing load on an indicating instrument.

50. Describe in detail the best methods of arriving at an average reading of a fluctuating load from the record of a graphic recording instrument.

51. What is the function of a maximum load indicator, and how is it used?

52. What is the difference in the methods of connecting in circuit:
(*a*) A voltmeter?
(*b*) An ammeter?
(*c*) The current coils of an indicating watt-meter?

53. Give five precautions to be observed by an assistant in handling and setting up instruments for tests.

54. When testing with indicating instruments, why should the potential for instruments be tapped in ahead of the watt-hour meter under test?

55. If powerful magnets, or wires carrying heavy currents are close to a watt-hour meter, or instrument, will the accuracy be affected and why?

56. State how to test for effective stray fields on continuous current circuits where the watt-hour meters are already installed.

57. If you were sent to investigate a consumer's complaint on account of a high bill, how would you conduct the investigation?

58. What information would you obtain in making an investigation on a consumer's complaint, where the installation included lamps, motors and heating appliances?

59. If you discovered that the cause of the abnormal registration involved the theft of current, what would you do?

60. How would you test the consumer's installation and circuits for grounds when making a complete test?

61. What tests would you make to determine if all the consumer's load is being properly metered, when the house wiring is concealed?

62. How is the correct consumption of energy determined if a watt-hour meter is found to be a certain per cent fast or slow?

63. (*a*) Show by sketch the star and delta methods of transformer low-tension winding connections for three-phase circuits.

(*b*) If the high-tension winding voltage is the same in both cases, how will the low-tension winding voltage compare in both methods?

64. What precautions should be taken in testing watt-hour meters which operate with instrument transformers? Why?

65. If an induction watt-hour meter is calibrated for 60 cycles, how would the accuracy be affected if used on a 140 cycle circuit?

66. (*a*) How will an ampere-hour meter register on a single-phase, alternating current motor, and why?

(*b*) With what accuracy will it register the true energy?

67. (*a*) How will a single-phase induction watt-hour meter operate on a non-inductive load if the potential coils are connected to one phase and the current coils to the other phase of a two-phase circuit?

(*b*) With the meter so connected, how would an inductive load affect its operation?

68. Make diagrams illustrating the internal connections of the various makes and types of the watt-hour meters used by your company.

69. (*a*) To what tests should a watt-hour meter be subjected in order to determine its acceptability as a type?

(*b*) What are the limits of error allowed in the above tests?

(*c*) What are the most desirable characteristics which constitute a commercially satisfactory service watt-hour meter?

70. Why will a shunt motor increase in speed when the field strength is decreased, while a meter will decrease in speed?

71. Why are meters not radically affected by temperature changes?

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